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Ogden, UT 84401

Research Paper
INT-334

January 1985

Response of Grass Species to Tree Harvesting in Singleleaf Pinyon-Utah Juniper Stands

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RESEARCH SUMMARY

Cover, yield, and nutrient concentrations of grasses were sampled on tree-harvested and nonharvested plots on north, west, and south aspects of a singleleaf pinyon (*Pinus monophylla*)-Utah juniper (*Juniperus osteosperma*) stand. Grass cover increased rapidly the first 2 years following tree harvest, but the rate of increase declined over the next 2 years. Grass yield varied among aspects and soil microsites on tree-harvested plots but not on the nonharvested plots where tree competition masked aspect and microsite effects. All grass species had greater yield and greater percentage nitrogen and phosphorus on harvested than on nonharvested plots. Low digestibility of some species may reduce potential livestock gains. On tree-harvested plots, the tree-associated microsites (duff and transition) had higher grass yield per unit area than the interspace microsites between trees. Tree harvesting decreased the area required per animal unit month from 27 to 7 acres (11 to 3 ha) (north) and 42 to 5 acres (17 to 2 ha) (west), but had no effect on the south aspect (40 acres, or 16 ha). Protein levels were adequate for livestock on tree-harvested plots (north and west) but below levels recommended for deer.

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INTRODUCTION

An inverse relationship between tree cover and forage production is well established for several forest systems including the pinyon-juniper woodlands of the West (Jameson 1967; Clary 1969). Thinning or clearcutting small patches of trees has been suggested to increase production and quality of forage for wildlife and livestock (Patton 1974), but cutting must be balanced with the appropriate management of the wood resource. Currently little is known about understory response following tree harvest in the pinyon-juniper woodlands of the Great Basin. Understory production has increased following removal of juniper species in the Southwest, but there are large variations due to soils and climate (Jameson and Dodd 1969; Clary 1974).

Understory species composition and cover vary among soil microsites found within pinyon-juniper stands (Harner and Harper 1976; Everett and Koniak 1981). Understory composition and distribution patterns are closely tied to tree cover and associated soil characteristics (Everett and others 1984). Barth (1980) demonstrated nutrient enrichment in soil microsites under the tree crown of pinyon (*Pinus edulis* Engelm.) and the depletion of nutrients from the interspace microsites among tree stems.

Understory production, protein levels, and mineral concentrations may increase under the crowns of semiarid shrubs in response to increased soil nutrients and shading effects (Rickard and others 1973). Under mesic forest conditions, forage production and digestibility may decline with increasing overstory cover, but protein concentrations may increase (Laycock and Price 1970). Climate of the singleleaf pinyon (*Pinus monophylla* Torr. and Frem.)-Utah juniper (*Juniperus osteosperma* [Torr.] Little) woodland is intermediate between these two vegetation types, and forage quality and quantity differences among soil microsites are unknown.

Microsites that produce more nutritious forage are particularly important to selective feeders like deer (*Odocoileus* sp.) that must depend on high quality forage because of their limited rumen capacity (Hanley 1982). Utilization of forage by livestock and wildlife is directly related to nitrogen and phosphorus levels in plants and soils (Van Soest 1982). Increases in nutrient concentrations of forage among soil microsites may increase intake and animal gains.

Protein, phosphorus, and energy usually limit animal nutrition on western ranges (Halls 1970; Cook and Harris 1977). Ruminants feed until energy requirements are met or their rumen is full. Consequently nitrogen and phosphorus uptake depends on their concentrations in consumed forage.

Grass yield from woodland sites is a hierarchial phenomenon: (1) individual species yield, (2) composite species yield by soil microsite, and (3) composite microsite yield by site. This study assessed forage quality differences of grass species on tree-harvested and nonharvested plots and among soil microsites that occur on those plots. We chose to sample yield at plant maturity and forage quality at the anthesis phenologic stage. We asked: (1) What effect does tree harvesting have on individual species yield and nutritional quality? (2) What changes in grass yield and quality occur on individual soil microsites? (3) What is the total nonharvested and harvested plot yield available to cow-calf pairs and wildlife that use the sites?

Change in forage quality over time has been adequately documented for many of the grass species in this study (Murray and others 1978). Although exact timing of nutrient changes may differ between study areas, decline in forage quality over time has been sufficiently established in the literature to have already been made into a basic range management concept (Vavra and Raleigh 1976) and therefore these trends need not be restudied here.

METHODS

Study Site

We chose a study area with a simple floristic composition and sufficient grass understory to demonstrate a response to tree release. The study area was a singleleaf pinyon-Utah juniper woodland approximately 2.5 mi (4 km) northeast of Ione in the Shoshone Mountain range of west-central Nevada. Similar areas occur on several mountain ranges in western Nevada.

Basalt-andesitic derived soils were classified as clayey, skeletal, mixed, frigid, Lithic Xerollic Haplargids (USDA 1975). These soils are depleted of nutrients in the interspace between trees and are enriched under the tree crowns (Everett 1984). Precipitation during the study was:

Year	Inches	(mm)
1979	9.5	240
1980	12.6	320
1981	11.8	300
1982	13.0	330
1983	17.3	439

These are estimates from the mean of the two closest official weather stations in the same vegetation type (Reese River Valley and Austin).

One tree-harvested and one nonharvested plot were established adjacent to each other on north (N. 20° E.), west (S. 84° W.), and south (S. 16° E.) aspects. Square tree-harvested plots (0.25 acre [0.1 ha] in size) were cleared of all trees 3.3 ft (1 m) in height. Cut trees, including slash, were removed from the plot. Adjacent nonharvested plots (0.1 ha in size) were left undisturbed, and both tree-harvested and nonharvested plots were fenced to exclude livestock. Sampled aspects were within 1.29 mi (2 km) of each other on 14 to 18 percent slopes at a mean elevation of 7,580 ± 100 ft (2 310 ± 30 m).

The soil surface in the woodland was a mosaic of soil microsites. Tree litter (duff) greater than 0.3 inch (0.5 cm) in depth occurred under the tree crown. A transition zone of light needle cover (less than 0.5 cm in depth) formed a halo at the crown edge. And bare mineral soil occurred in the interspaces between trees (Everett and Sharrow 1983). Microsites with needle cover (duff and transition) occupied 50, 72, and 70 percent of the ground surface of north, west, and south aspects, respectively.

The three plant assemblages sampled were: *Pinus monophylla*/*Purshia tridentata* (Pursh) D.C. (antelope bitterbrush)/*Festuca idahoensis* Elmer (Idaho fescue)/*Lupinus caudatus* Kellogg (tailcup lupine) on the north aspect; *Pinus monophylla*/*Artemisia arbuscula* Nutt. (low sagebrush)/*Poa sandbergii* [Steud.] Vasey (Sandberg bluegrass)/*Trifolium gymnocarpon* Nutt. (hollyleaf clover) on the west aspect; and *Pinus monophylla*/*Artemisia tridentata* ssp. *wyomingensis* Nutt. (Wyoming big sagebrush)/*Poa sandbergii*/*Microsteris gracilis* (Hook.) Greene (microsteris) on the south aspect (Everett and others 1984). At the time of tree harvest the ratio of tree to grass cover was 28/3 percent, 61/2 percent, and 54/1 percent on north, west, and south aspects, respectively.

Cover, Density, and Biomass

In 1979 species cover and plant density of Sandberg bluegrass, squirreltail (*Sitanion hystrix* [Nutt.] J. G. Smith), Idaho fescue, and junegrass (*Koelaria cristata* [L.] Pers.) were estimated on harvested plots immediately before trees were removed. Sampling was repeated on both tree-harvested and nonharvested plots in 1981 and 1983. Crown cover and number of plants for each grass species were estimated with 20- by 20-inch (50- by 50-cm) frames laid at every meter mark on five permanent parallel transects of 66 ft (20 m) in length and 16 ft (5 m) apart in each tree-harvested and nonharvested plot. In 1981 grass yield was estimated on these permanent transects in nonharvested and tree-harvested plots. Leaf weight estimates were made separately for each grass species in each frame using the weight estimate double sample method (Pechanec and Pickford 1937; Wilm and others 1944). Of each grass species, 20 samples were clipped at maturity, seed heads discarded, and estimates made of dry weight. Samples were ovendried, weighed, and regression equations derived ($r^2 = 0.81$ to 0.96). Yield (ovendry weight) was calculated from the regression of weight estimates made in the field.

Forage Quality

In June 1980 we collected at random 20 plants of each species in each tree-harvested and nonharvested plot where they occurred in abundance. All species were sampled at the anthesis stage of development. Sampling was refined in 1981, and eight plants of each species (anthesis stage) were harvested from each of the soil microsites, duff, transition, and interspace, on each tree-harvested and nonharvested plot. Grass samples were clipped at 0.4 inch (1 cm) height and seed heads were removed. Leaves were ovendried at 117 °F (47 °C) and ground to pass through a 0.5-mm sieve.

Plant materials collected in 1980 were run in duplicate through in vitro digestibility trials (Tilley and Terry 1963) using rumen inoculum from heifers maintained on a grass hay diet. Plant materials for 1981 were analyzed in duplicate for in vitro digestibility, total Kjeldahl nitrogen-salicylic acid modification (Eastin 1976), and phosphorus (sulfuric acid digest-colorimetric procedure using ascorbic acid indicator: Watanabe and Olsen 1965). Duplicate samples not within 10 percent of their mean value were rerun. A standard forage sample was included in each run and each run was adjusted to every other run via the common standard. Gross energy of each species was determined from four composite subsamples with a Parr adiabatic bomb calorimeter. Digestible energy (DE) was computed by microsite and whole plots using the formula DE = Production (i) * Gross Energy (i) * Dry Matter Digestibility (i) for each (i) species, as suggested by Conroy and others (1982).

Analysis

The experimental unit was the individual plant (20-24 replicates) when we tested for differences in in vitro digestibility, percentage of phosphorus, and percentage of nitrogen between harvested and nonharvested plots. In comparisons of the above parameters among soil microsites there were eight replicates per harvested and nonharvested plot. Belt transects (five replicates) were subdivided into individual soil microsite components, duff, transition, and interspace. Microsite area per transect served as the experimental unit. Differences in yield and forage quality among microsites were evaluated on a per-unit-area basis. The three replicates of paired harvested and nonharvested plots served as the experimental units in the comparison of the composite microsite change in forage yield and quality following tree harvest.

Analysis of variance and Hartley's sequential method of testing (Snedecor 1956) were used collectively to test for differences in total grass cover among years and individual species differences in yield, percentage nitrogen and phosphorus, in vitro digestibility, and plant density. Orthogonal contrasts were used to test for differences in forage quality (digestible dry matter, digestible energy, protein [6.25 × %N] and phosphorus) among microsites and tree-harvested treatments.

RESULTS AND DISCUSSION

Species Yield and Plant Density

All plant species examined showed a numerical increase in yield on tree-harvested plots, although differences were not always statistically significant (table 1). Except for squirreltail (west) and Idaho fescue (north), the greater yield on tree-harvested plots was the result of increased growth per plant and not increased plant density.

Squirreltail biomass and plant density increased on the tree-harvested plot of the west aspect. The species was barely represented on nonharvested plots but rapidly occupied the duff microsite following tree removal (Everett and others 1984). Robust growth of squirreltail following tree felling was previously reported by Clary and Morrison (1973) for alligator juniper (*Juniperus deppeana* Steud.) woodlands. Idaho fescue dominated the understory of the north aspect on nonharvested and tree-harvested plots.

Table 1.—Grass yield and plant density [illegible] and nonharvested [illegible] plots by aspect

Grass	Yield		Density	
	Nonharvest	Harvest	Nonharvest	Harvest
	Lb/acre		[illegible]	
		South		
Sandberg bluegrass	24.9	[illegible]	[illegible]	[illegible]
		West		
Sandberg bluegrass	14.3	59.6*	1	[illegible]
Squirreltail	0	274.5*	1	4
Idaho fescue[2]	8.9	10.7	1	1
		North		
Sandberg bluegrass	4.5	52.1*	4	[illegible]
Squirreltail	12.5	13.4	1	[illegible]
Idaho fescue	39.5	151.7*	[illegible]	[illegible]

[1] (*) significantly [illegible] on tree-harvested than nonharvested plots.
[2] Junegrass plants were present but [illegible] analysis.

Species Forage Quality

In vitro digestibility of grass on tree-harvested plots was greater or equal to that on nonharvested plots for Sandberg bluegrass and Idaho fescue (north). Digestibility of squirreltail, junegrass, and Idaho fescue (west) was similar or lower on tree-harvested than on nonharvested plots (table 2). Apparent contradictory reports of digestibility increasing (Duvall 1970), remaining unchanged (Conroy and others 1982), or declining (Laycock and Price 1970) following tree harvest appear justified. We found digestibility increased and decreased among species growing on the same site. A general decline in digestibility of grasses on our sites occurred from 1980 to 1981.

Based on averages of data, species digestibility was in the general order of Sandberg bluegrass = junegrass > squirreltail > Idaho fescue (table 2). Wallace and others [illegible]

Table 2.—[illegible]

Grass	1980		1981	
	Nonharvest	Harvest	Nonharvest	Harvest
		[illegible]		
		South		
Sandberg bluegrass	[illegible]	[illegible]	[illegible]	[illegible]
		West		
Sandberg bluegrass	[illegible]	[illegible]	[illegible]	[illegible]
Squirreltail	[illegible]	[illegible]	[illegible]	[illegible]
Junegrass	[illegible]	[illegible]	[illegible]	[illegible]
Idaho fescue	[illegible]	[illegible]	[illegible]	[illegible]
		North		
Sandberg bluegrass	[illegible]	[illegible]	[illegible]	[illegible]
Idaho fescue	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible] National Research [illegible] cies on tree-harvested sites and for squirreltail.

Table 3.—[illegible] nitrogen and phosphorus [illegible] on tree-harvested and nonharvested [illegible] aspects

Grass	Nitrogen		Phosophorus	
	Nonharvest	Harvest	Nonharvest	Harvest
		Percent		
		South		
Sandberg bluegrass	1.04	[illegible]	0.12	[illegible]
		West		
Sandberg bluegrass	[illegible]	[illegible]*	[illegible]	[illegible]
Squirreltail	1.50	[illegible]	.27	[illegible]
Junegrass	1.42	1.64	.30	.31*
Idaho fescue	1.15	[illegible]*	[illegible]	.21
		North		
Sandberg bluegrass	[illegible]	[illegible]*	[illegible]	[illegible]
Idaho fescue	[illegible]	[illegible]	.20	[illegible]

*Significant [illegible] differences between [illegible] harvested and [illegible] junegrass, and Idaho fescue (north aspect) on nonharvested sites. But nitrogen levels of all species remained below recommended levels for the nutritional needs of deer (16 percent protein ≅ 2.56 percent N: Halls 1970; Verme and Ullrey 1972).

Percentage phosphorus (P) was numerically greater on tree-harvested plots for all species (except squirreltail) and significantly so ($p = 0.1$) for Sandberg bluegrass and junegrass. Minimum phosphorus requirement for lactating cows of 1,100 lb (500 kg) is 0.28 percent P (National Research Council 1976). This value would be marginally adequate for deer nutritional needs as well (Verme and Ullrey 1972).

Soil Microsite Impact on Species

We were unable to determine differences ($p = 0.1$) in percentage nitrogen or percentage phosphorus of grass species growing on different microsites in tree-harvested or nonharvested plots. Our results are at variance with other reports of increased percentage nitrogen levels in grasses under semiarid shrubs (Rickard and others 1973) or mesic tree cover (Holecheck and others 1981). We speculate that on our tree- harvested plots, the increased grass yields (table 1) of the tree-associated microsites diluted nutrient concentrations. On our nonharvested plots, uniform moisture stress (Everett and Sharrow, unpublished) may have limited nutrient uptake and plant growth equally among microsites.

Composite Forage Response by Soil Microsite

We found no yield differences among soil microsites on any of the nonharvested plots, and grass yield was not different ($p = 0.1$) for individual microsites among aspects. Tree dominance was sufficiently intense to mask inherent microsite differences that emerged following tree removal.

Grass yield was greater on tree-associated microsites (duff and transition) than in interspace on west and north tree-harvested plots. Grass yield was not different among microsites on the south aspect (table 4). Yields of interspace microsites on tree-harvested plots were consistently similar to interspace yields on nonharvested plots.

Composite Forage Response by Aspect and Harvest Treatment

We caution that because aspect plots were not replicated, statistical results apply only to these specific plots. These plots are, however, characteristic of the population of pinyon-juniper communities from which they were drawn.

Grass cover increased for 2 years (1979 and 1980) following tree harvest on north and west aspects, but the rate of increase declined the next 2 years (fig. 1). Cover on nonharvested plots increased to a lesser extent from 1979 to 1983 and may reflect the effect of livestock exclusion on the site. The large peak in cover on the west aspect in 1981 reflects the rapid dominance and decline of squirreltail following tree harvest.

Table 4.—Total grass yield (lb/acre) by soil microsite on tree-harvested and nonharvested plots on south, west, and north aspects

Aspect	Nonharvest			Harvest		
	D[1]	T	I	D	T	I
	Lb/acre					
South	41.1^{a}[2]	41.1^{a}	31.2^{a}	26.1^{a}	39.3^{a}	41.9^{a}
West	31.2^{bc}	41.1^{bc}	14.3^{bc}	574.7^{a}	334.6^{a}	97.3^{b}
North	31.2^{c}	43.7^{bc}	33.9^{c}	205.2^{ab}	223.1^{ab}	169.5^{abc}

[1] D = duff, T = transition, I = interspace microsites.

[2] Superscripts (a,b,c) denote significant ($p = 0.05$) differences between microsites on the same aspect for harvested and nonharvested plots.

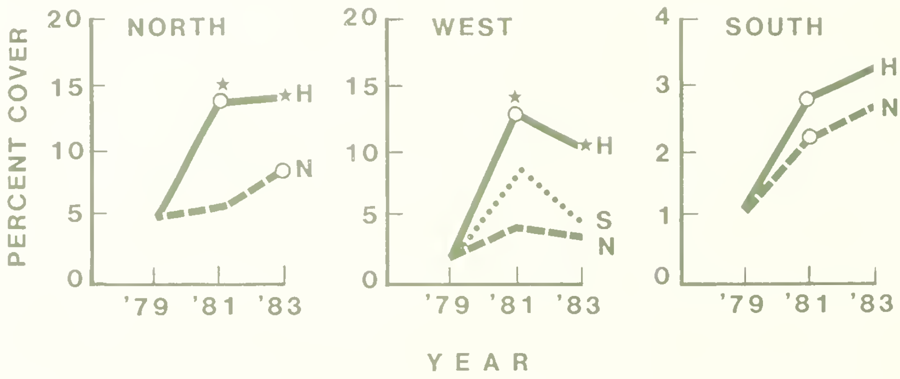

Figure 1.—Percentage grass cover on tree-harvested (H) and nonharvested (N) plots on north, west, and south aspects over time. (*) denotes significant ($p = 0.05$) differences between harvested and nonharvested plots in the same year. (O) denotes significant differences in cover from the preceding year on the same plot. (S) refers to cover of squirreltail (Sitanion hystrix).

Yield of dry matter, digestible dry matter, digestible energy, protein, and phosphorus was greater on tree-harvested than on nonharvested plots on north and west aspects (table 5). Yield was similar on tree-harvested and nonharvested plots of the south aspect. O'Rourke and Ogden's (1969) suggestion that high tree cover is an indication of potentially high understory production did not hold in this instance (tree cover 28 percent north vs. 54 percent south). Tree cover had not yet stabilized on the north aspect (Meeuwig and Cooper 1981). The reported loss in production of cool season grasses following tree harvest in Arizona (Clary and Morrison 1973) did not occur here. Basic climatic differences exist between the two woodland systems.

The "minimal area" required to provide the daily digestible energy requirement for a 1,100-lb (500-kg) lactating cow (24.41 Mcal DE, National Research Council 1976) utilizing 50 percent of the grass yield varied from 1.43 acres (0.58 ha) on nonharvested plots to 0.15 acre (0.06 ha) on tree-harvested plots (table 5). A [illegible]

Table 5. Yield of dry matter, digestible dry matter, digestible energy, protein and phosphorus [illegible] and tree-harvested sites for [illegible] south, west, and north aspects

Aspect	Nonharvest	Harvest
	Dry matter	
	Lb/acre	
South	[illegible]	[illegible]
West	[illegible]	[illegible]
North	[illegible]	[illegible]
	Digestible dry matter	
	Lb/acre	
South	[illegible]	[illegible]
West	[illegible]	[illegible]
North	[illegible]	[illegible]
	Digestible energy	
	[illegible]	
South	[illegible]	[illegible]
West	79.09	[illegible]
North	51.53	[illegible]
	Minimal grazed area[2] (acres/animal/day 50% utilization)	
South	1.28	1.28
West	1.43	.15
North	.59	[illegible]
	Protein	
	Lb/acre	
South	2.3	[illegible]
West	2.1	[illegible]
North	[illegible]	[illegible]
	Phosphorus	
	Lb/acre	
South	0.04	[illegible]
West	.06	.27
North	.07	.45

[1] Significantly [illegible] nonharvested and harvested [illegible]

[2] Minimal grazed area [illegible] energy to meet the [illegible] lactating cow.

[illegible]

CONCLUSIONS

[illegible]

All species (Sandberg bluegrass, squirreltail, Idaho fescue, and junegrass) increased in yield, nitrogen, and phosphorus following tree harvest. Thus, forage quantity and quality are expected to increase following tree harvest regardless of the exact species composition. Differences in digestibility among grass species suggest that grass yield conversion to livestock gains may be overestimated when species with low digestibility predominate.

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Tree harvesting in pinyon-juniper woodlands increases grass yield and quality. Yield per unit area was greater on tree-associated soil microsites than in the interspace between cut stems. All grass species had higher nitrogen and phosphorus levels following tree removal. Tree harvesting reduced the area required per animal unit month from 27 to 7 acres (11 to 3 ha) (north aspect) and 42 to 5 acres (17 to 2 ha) (west aspect), but had no effect on the south aspect (40 acres, or 16 ha). Tree harvesting is a viable method to increase forage production for livestock and wildlife.

KEYWORDS: pinyon, juniper, tree harvest, understory response, forage quality

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Forest and Range
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Research Paper
INT-335

June 1985

Reclamation on Utah's Emery and Alton Coal Fields: Techniques and Plant Materials

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NOV 25 1985
PUBLIC DOCUMENT

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the U.S. Department of the Interior, Bureau of Land Management, in providing the sites on which these studies were made. We especially thank Richard C. Jewell, Hydrologist; Jesse M. Purvis, Hydrologist; Samuel R. Rowley, San Rafael Resource Area Manager; and Larry G. Sip, currently Henry Mountain Resource Area Manager.

Acknowledgment is also made of the cooperation of Utah International, Incorporated, San Francisco, Calif., in providing seed and fencing at two of the study sites on the Alton coal field.

Financial support for these studies was provided by the USDI, Bureau of Land Management under Interagency Agreement No. UT-910-1A0-007, the U.S. Environmental Protection Agency under Interagency Agreement No. DE-E764, and Utah International, Incorporated.

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RESEARCH SUMMARY

The studies reported on in this paper were designed to provide information on methods to establish vegetation on the soils of the semiarid Emery and Alton coal fields in Utah. No large-scale surface mining of coal has occurred in Utah, so research was conducted on typical potential mine sites following severe disturbance of soil materials. At Emery, primary objectives of the several studies were to evaluate the relative merits of site preparation by gouging, harrowing, and cultipacking in conjunction with the use of alfalfa hay or composted conifer bark as soil amendments. Seed was planted by broadcasting in all trials. At Alton, gouging and the use of hay and composted conifer bark was also tested. Wide varieties of plant species, consisting primarily of shrub and grass species but including several forb and tree species, were planted on different soil materials at both coal field locations.

Secondary objectives on both study areas were the evaluation of the use of container-grown shrubs and determination of soil water potentials and soil temperature regimes, as well as a documentation of air temperature and precipitation amounts received during the study period.

During 5 years at Emery and 6 years at Alton, data were obtained on vegetational parameters such as density, percent cover, and plant yield. Data on survival and growth were obtained on planted shrubs.

Major findings at Emery were as follows: The first-year establishment of seeded grasses and shrubs was greater on areas that were lightly harrowed following broadcast seeding than on areas cultipacked following seeding or where seeding and gouging were done simultaneously. However, yields were subsequently higher on areas seeded with the gouger-seeder than on harrowed or cultipacked areas. Grass establishment was enhanced by the incorporation of alfalfa hay into the top 6 to 8 inches (15 to 20 cm) of soil prior to seeding. The addition of composted conifer bark to the soil inhibited initial grass establishment. The yield of perennial grasses was similar on topsoil and subsoil of both the Penoyer and Persayo soil series, whereas grass and shrub establishment on topsoil of the Castle Valley soil series was greatly superior to that on subsoil. The Penoyer soil series supported a more vigorous stand of grasses than soil of the Persayo series. Excellent establishment of container-grown shrub species was obtained at Emery when plants were watered at the time of planting and at 2- to 3-week intervals during the first growing season. Species of *Atriplex* were especially well adapted. Fourwing, Bonneville, broadscale, and trident saltbushes, plus prostrate summercypress, Mediterranean camphorfume, winterfat, and plumed white sage can be recommended for use on all soil materials studied at Emery.

Major findings at Alton were as follows: The incorporation of grass hay into the soil prior to seeding increased the initial establishment of seeded species. However, use of a hay soil amendment in the Alton area is not recommended when topsoil of satisfactory quality is available. Adequate vegetative stand density can be established to protect the soil from erosion on slopes of 15 percent or less by gouging the soil surface followed by broadcast seeding. 'Nomad' alfalfa, fourwing saltbush, bitterbrush, and cliffrose are capable of persisting in competition with perennial grasses on soils of this area, although the latter two species probably won't contribute significant amounts of forage until the fifth or sixth year. "Introduced" species of grass can be expected to outyield "native" species for the first 3 or 4 years following seeding. However, by the fifth or sixth year, well-adapted native species should equal most introduced species in herbage yield. Perennial grass species that appear well adapted to the climate and soils of the Alton coal field are basin wildrye, 'Alkar' tall wheatgrass, 'Whitmar' beardless bluebunch wheatgrass, intermediate wheatgrass, smooth bromegrass, 'Luna' pubescent wheatgrass, 'Fairway' crested wheatgrass, and 'Nordan' crested wheatgrass. Sandy loam topsoil of the fine-loamy Typic Argiustolls subgroup is perhaps best for use on the surface of reclaimed areas of the Alton coal field. A variety of shrub and tree species can be successfully established on soils of this area by planting container-grown seedlings prior to May 15. Supplemental watering should only be necessary at the time of planting. Fourwing saltbush ecotypes from southern Arizona and southern California have little chance to survive in the Utah location because of lack of winter hardiness. Shrub survival and growth are better when shrubs are established in stands of perennial bunchgrass than when forced to compete with vigorous rhizomatous species.

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Reclamation on Utah's Emery and Alton Coal Fields: Techniques and Plant Materials

Robert B. Ferguson
Neil C. Frischknecht

INTRODUCTION

In the United States today more and more people recognize that fossil fuels must be extracted for the national welfare. As the need for coal increases, additional lands will be mined. In Utah, coal-bearing formations such as those in the Emery and Alton coal fields will be partially or entirely mined from the surface. Surface mining must be done in a manner that minimizes environmental damage. Restoration of vegetative cover on severely disturbed land is usually the only practical, long-term way to stabilize reshaped surface-mined lands and to return them to other productive use. Some areas may be reclaimed in a way that will make them more productive and useful than they were prior to mining.

Areas potentially suitable for the surface mining of coal in Utah are predominantly in arid or semiarid climatic environments, with mean annual precipitation ranging from 7 to 17 inches (180 to 430 mm). Adding to the harshness of the environment is the extreme variability of the precipitation pattern, which often results in lack of adequate soil moisture for seed germination and plant survival. However, high intensity rainstorms in these arid areas necessitate having good vegetative cover to prevent soil loss, downstream flooding, and sedimentation problems.

This report discusses recent research on alternative techniques that could be useful in revegetating lands disturbed by mining in the Emery and Alton coal fields. Because no surface coal mines currently exist on either the Emery or Alton coal fields, this research was limited to treatments that could be applied following severe disturbance with heavy equipment. We hope the results of this work will aid those involved in the planning, operation, use, and management of future mining and revegetation efforts.

PART I: RESEARCH ON THE EMERY COAL FIELD

STUDY AREAS

The Emery coal field lies in central Utah to the east of the Wasatch Plateau, in Emery County. It is in the northwest corner of the Canyonlands section of the Colorado Plateau province (Thornbury 1965). The study area is on the western edge of a region known as the Coal Cliffs, which, in turn, is the western edge of the San Rafael Swell. Individual study sites are located from 4 to 5 mi (6.4 to 8 km) southeast of the town of Emery at elevations between 6,100 and 6,450 ft (1 850 to 1 966 m). Location of these sites is shown in appendix figure 61.

Vegetation on the Emery coal field varies from salt desert shrub communities in the lower areas to pinyon-juniper communities at higher elevations. Typical dominant plant species of local salt desert shrub vegetation are Castle Valley clover (*Atriplex cuneata* A. Nels.), mat saltbush (*Atriplex corrugata* S. Wats.), shadscale (*Atriplex confertifolia* [Torr. & Frem.] S. Wats.), Indian ricegrass (*Oryzopsis hymenoides* [R.&S.] Ricker), greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.), fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.), galleta grass (*Hilaria jamesii* [Torr.] Benth.), blue grama (*Bouteloua gracilis* [H.B.K.] Lag. ex Steud.), alkali sacaton (*Sporobolus airoides* Torr.), and prickly pear (*Opuntia* spp.). As one enters the pinyon-juniper type, characterized by Utah juniper (*Juniperus osteosperma* Hook.) and pinyon (*Pinus edulis* Engelm.), the same grasses are found, plus small shrubs such as black sagebrush (*Artemisia nova* A. Nels.), Bigelow sagebrush (*Artemisia bigelovii* Gray), green ephedra (*Ephedra viridis* Cov.), and corymbed eriogonum (*Eriogonum corymbosum* Benth.).

Soils of the Emery coal field are derived primarily from the Ferron sandstone member of the Cretaceous, Mancos shale formation. The Ferron sandstone is fine to coarse, marine sandstone. All coal in the Emery area occurs in the lower unit of the Ferron sandstone member, which contains intercalated beds of shale, siltstone, and coal. Locally, soils vary from silty clays to loams and very fine sandy loams, having a soil pH range of 7.4 to 8.4, and conductivity values of 2 to 16 mmhos per centimeter. Soils of the individual study sites will be discussed in detail in subsequent sections of this report.

The Emery coal field lies in the rain shadow of the Wasatch Plateau, the northernmost of the High Plateaus of Utah, which rises to the west. Average annual precipitation for most of the coal field area is between 6 and 10 inches (150 and 250 mm). November through April constitutes the driest portion of the year, with each month of the period consistently averaging about 0.45 inches (11.4 mm) of precipitation. May through October constitute the "wet" months, each of which averages about 0.80 inches (20 mm) of precipitation. Historically, August and October have recorded the most precipitation events of 0.2 inches (5 mm) or more. Richardson (1975) says the frost-free growing season averages 132 days at the town of Emery, 6,250 ft (1 905 m) in elevation.

METHODS

On three soil series at Emery, we varied the site preparation and type of soil amendment. We then seeded a mixture of grasses and shrubs believed adapted to the environment. Numerous shrub species and some additional grass and forb species were tested on plots separate from the seeded areas. Data were taken on plant establishment, productivity, and, in the case of shrubs and forbs, on survival and growth rate.

Site Preparation and Soil Amendments

Successful establishment of plants by direct seeding is difficult in areas receiving less than 10 inches (250 mm) of annual precipitation, so we needed to evaluate different methods of seeding. Further, we wanted to know whether the addition of an organic soil amendment would aid plant establishment and growth by increasing available soil moisture and nitrogen. A third objective was to compare the success of selected species of grasses and shrubs sown together.

This phase of the research at Emery was done on each of three different soil series that were found within the area available for research experiments: the Persayo, Penoyer, and Castle Valley series (USDA 1978).

Soils of the Persayo series are calcareous, well drained, and moderately fine textured. They are residual soils, formed from shale, and support a vegetation usually dominated by galleta and shadscale. In a typical profile the surface 1 inch (2.5 cm) is a loam, underlain by up to 12 inches (30 cm) of loam and silty clay loam. The soil is strongly calcareous and mildly alkaline (pH 7.5 to 7.7). The part of the profile below 10 inches (25 cm) is normally silty clay loam that contains less than 35 percent clay. Weathered fragments of shale make up 5 to 70 percent of the material below 10 inches depth.

Soils of the Penoyer series are also calcareous and well drained, but are medium textured. They have formed in alluvium from sandstone, limestone, and basic igneous rocks. Dominant plant species on Penoyer soils are sagebrush, Indian ricegrass, galleta, and shadscale. In a typical profile the surface layer is a strongly calcareous loam about 9 inches (23 cm) thick. Underlying material is loam, silt loam, or very fine sandy loam. The soils are strongly calcareous and mildly to moderately alkaline (pH 7.7 near the surface to 8.2 below). The subsoil below 10 inches contains less than 18 percent clay.

The Castle Valley series consists of shallow, calcareous, well-drained soils found on upland benches and mesas. They have formed from weathered sandstone and interbedded shale, and support pinyon, juniper, big sagebrush, black sagebrush, and Indian ricegrass as the dominant vegetation. In a typical profile the surface layer is a loamy, very fine sand, with a subsoil of gravelly, very fine sandy loam, containing lime in the lower part. The soils are usually shallow with sandstone bedrock at a depth of about 10 inches (25 cm). The soils are slightly calcareous and mildly alkaline (pH 7.6). Flat, angular pieces of sandstone make up from 15 to 50 percent of the volume of the subsoil.

In autumn 1977, three sites were selected and treated: a 6-acre (2.4-ha) tract on Persayo soil, a 4-acre (1.6-ha) tract on Penoyer soil, and a 2-acre (0.8-ha) tract on Castle Valley soil. On both the Persayo and Penoyer sites the topsoil was removed to a depth of 15 inches (38 cm), the subsoil ripped to a depth of 30 inches (76 cm) with a D-9 caterpillar tractor and releveled, and the topsoil replaced. On the Castle Valley soil, approximately 12 inches of topsoil was removed from one-third of the area. This section, and the remaining undisturbed portion of the area were then ripped to a 30-inch depth (fig. 1). No releveling of the ripped soil was attempted, nor was the topsoil replaced where it had been removed.

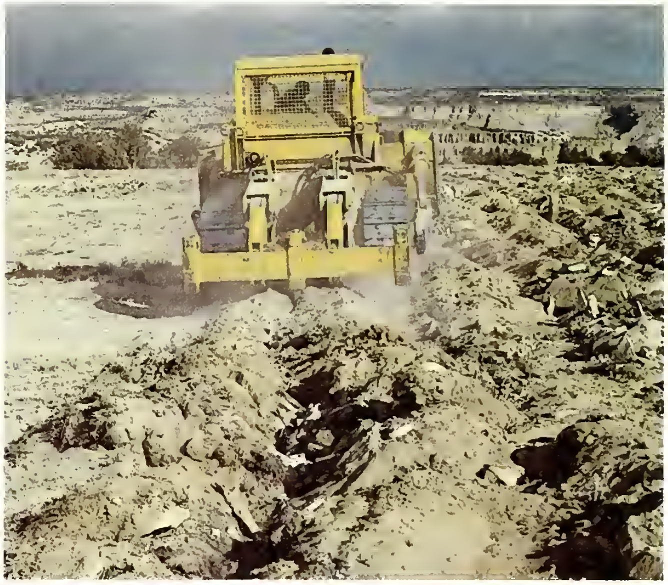

Figure 1.—Ripping Castle Valley series topsoil to a depth of 30 inches. Persayo and Penoyer subsoils were ripped in a similar manner following removal of 15 inches of topsoil. There the ripped subsoil was releveled and topsoil was replaced prior to seeding. December 1977.

Following the severe soil disturbance on the Persayo site, grass hay was rotovated into a 0.3-acre (0.12-ha) strip across the width of the site (fig. 2), and alfalfa hay was rotovated into the soil on two separate strips, one of 0.63 acre (0.25 ha), and one of 0.44 acre (0.18 ha). In addition, composted conifer bark was rotovated into the soil on a 0.1-acre (0.04-ha) strip across the width of the site. Both types of hay were applied at a rate of 2.5 tons per acre (5.6 tons/ha). The composted bark was spread over the surface of the soil to a depth of 1 inch before being mixed into the soil. The organic soil amendments were tilled into the top 8 inches (20 cm) of soil with a heavy duty rotovator developed at the Forest Service's Missoula Equipment Development Center.

On the Penoyer site, alfalfa hay and composted bark amendments were applied in a similar manner. However, no grass hay amendment was applied. On this site the hay was applied on two 0.36-acre (0.15-ha) strips, and the composted bark on one 0.07-acre (0.03-ha) strip across the width of the test area.

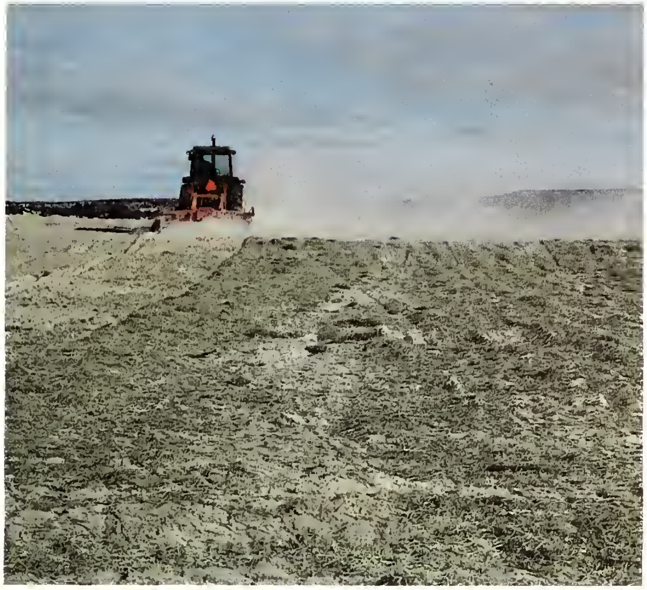

Figure 2.—Rotovating alfalfa hay into the top 8 inches of replaced topsoil on the Persayo soil study area at Emery. December 1977.

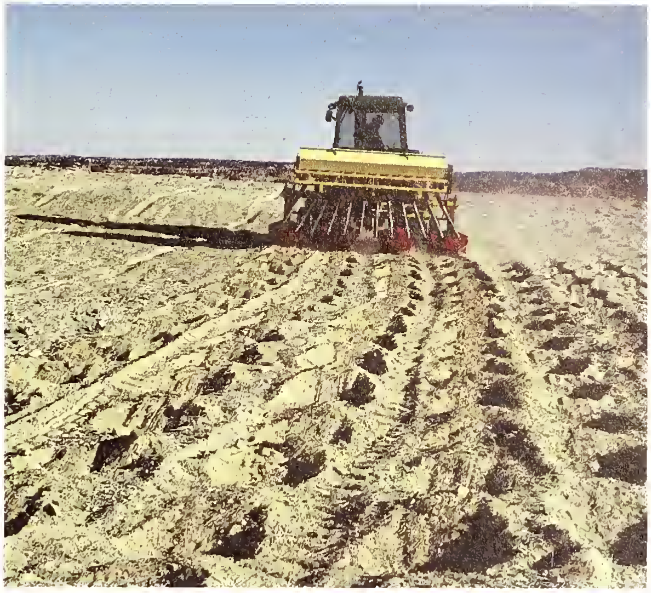

Figure 3.—At the Emery study area, seeding and gouging simultaneously with the gouger developed at the Missoula Equipment Development Center. December 1977.

Immediately after the application of organic soil amendments (none were applied to the Castle Valley site), seed mixtures were broadcast on all three sites, as outlined in table 1.

We used three seeding methods on both the Persayo and Penoyer sites: (1) the seed mixture was broadcast, using a hand-operated cyclone seeder, followed by harrowing with a spring tooth harrow; (2) seed was applied as above, followed by firming the seedbed with a small, Brillion cultipacker; and (3) seed was broadcast by a tractor-drawn gouger-seeder simultaneously with the gouging operation of part of the site (fig. 3). Because of the extremely rough, rocky surface of the Castle Valley site, seeding was done entirely with the hand-operated cyclone seeder, and no attempt was made to cover the seed or level and firm the seedbed. For the field design of these studies the reader is referred to appendix figures 41 and 42.

In July 1978, we obtained data on frequency, density, and average blade height of grasses (individual species were not recorded) on each treatment, on both the Persayo and Penoyer sites. At the same time, we recorded data on shrub frequency (all species combined), density of each shrub species, and average height of each shrub species. We used a rectangular-shaped, 10-ft^2 (0.929-m^2) frame placed at a number of randomly chosen locations within each treatment area. The sampling frame was subdivided by cross wires into ten 1-ft^2 (0.093-m^2)subplots. Percent frequency was obtained by recording the number of subplots in which the plant species or plant class being sampled was found, each time the frame was placed down.

In summers 1979 through 1982, vegetative sampling followed the same procedure with the following exceptions: (1) no data were taken on plant density, (2) frequency was recorded for all grasses as a group and for each species of grass and shrub, (3) average culm height was recorded for each grass species, (4) average height was recorded for each shrub species, and (5) yield of each grass and shrub species was estimated by the weight-estimate method (Pechanec and Pickford 1937).

Only visual observations of the results of deep ripping of the Castle Valley soil were made; no quantitative sampling was undertaken.

Table 1.—Composition of seed mixture sown on test sites of Persayo, Penoyer, and Castle Valley soils, Emery coal field

Common name	Scientific name	Source	Lb/acre
'Nordan' crested wheatgrass	*Agropyron desertorum*[1]	South Dakota	3
'Sodar' streambank wheatgrass	*Agropyron riparium*	Canada	3
Russian wildrye	*Elymus junceus*	Montana	3
'Paloma' Indian ricegrass	*Oryzopsis hymenoides*	Utah	2
Alkali sacaton	*Sporobolus airoides*	Kansas	1
Fourwing saltbush	*Atriplex canescens*	Sevier Co., UT	2
Nevada ephedra	*Ephedra nevadensis*	Beaver Co., UT	2
Winterfat	*Ceratoides lanata*	Sanpete Co., UT	2
Shadscale	*Atriplex confertifolia*	Utah	2

[1] Some 'Fairway' crested wheatgrass (*A. cristatum*) was included in the 3 lb/acre on the Penoyer soil.

We used analyses of variance and tests of mean separation to evaluate differences in vegetation results between treatments.

Soil Amendments and Herbaceous Species

We wanted to determine the effects of hay and composted bark amendments on the establishment and growth of selected grass species, and to compare the response of those species to the amendments on both topsoil and subsoil. So in November 1977, we delineated two areas 90 by 210 ft (27 by 64 m), one on the Persayo soil and one on the Penoyer soil. These areas had the topsoil removed and the subsoil ripped as previously described. However, each area was divided in half and topsoil only replaced and leveled on one half, with a 10-ft (3-m) buffer strip between the halves. Alfalfa hay was applied at the rate of 2.5 tons per acre (5.6 tons/ha) and rotovated into the top 8 inches (20 cm) of soil material on two 15-ft wide (4.6-m) strips extending across both the topsoiled and subsoil portions of each area. Composted bark was applied in a similar manner (fig. 4). The remaining one-third of each area served as a control.

On the Persayo soil, seed of 10 selected species was broadcast on subplots 10 by 15 ft (3 by 4.6 m) in size on each of the 15- by 100-ft (3- by 30-m) main plots, resulting in a randomized block, split-plot design with two replications.

Grass species selected for study are known for their adaptability to arid conditions. Species used and amounts of seed sown per plot are shown in table 2.

Seed was broadcast by hand on the loose, rough seedbed left by the rotovator. (The areas on which no soil amendment was applied were also rotovated.) On one of the two replications the subplots were raked with a garden rake following broadcasting of seed; no attempt was made to cover seed on the second replication.

The same species were sown on the Penoyer soil plots, but seed was not sown until March 1978. Soil was roughened by raking with a garden rake, and seed was then broadcast by hand. For the field design of these studies on Persayo and Penoyer soils, the reader is referred to appendix figures 43 and 44.

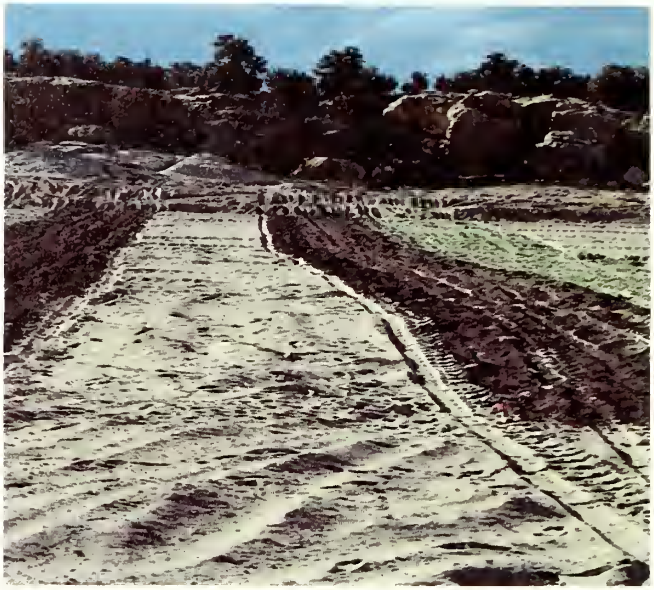

Figure 4.—Spreading composted conifer bark and alfalfa hay soil amendments on the Penoyer study area at Emery. Compost and hay were rotovated into the top 8 inches of soil prior to seeding. December 1977.

In spring 1978, virtually no seedlings of blue grama, alkali sacaton, or sand dropseed became established on plots of either Persayo or Penoyer soils. These plots were reseeded again in December 1978 with no success. In May 1980, on both the Persayo and Penoyer soils, 6-week-old container-grown plugs of these three species were planted on all subplots previously seeded to those species. Galleta grass was planted on the subplots previously seeded to Palmer penstemon, because the latter had established very poorly on many plots.

Beginning in 1978 we sampled the subplots of the six species of cool-season grasses at the same time and in the same manner as described for the seeding and soil amendment treatments. On each 10- by 15-ft subplot, we took two randomly located samples of 10 ft^2 (0.929m^2) each. In 1981 we took data on the percent survival and

Table 2.—Grass species used and amounts of seed sown on Persayo and Penoyer soils at the Emery coal field

Common name	Scientific name	Source[1]	Lb/acre
'Nordan' crested wheatgrass	*Agropyron desertorum*	South Dakota	10
Hybrid crested wheatgrass	*A. cristatum X A. desertorum*	[2]	10
'Fairway' crested wheatgrass	*Agropyron cristatum*	Montana	20
Russian wildrye	*Elymus junceus*	Montana	20
Indian ricegrass	*Oryzopsis hymenoides*	?	20
Squirreltail	*Sitanion hystrix*	Utah	20
Alkali sacaton	*Sporobolus airoides*	Kansas	10
Sand dropseed	*Sporobolus cryptandrus*	Kansas	10
Blue grama	*Bouteloua gracilis*	Kansas	10
Palmer penstemon	*Penstemon palmeri*	Utah	10
Galleta	*Hilaria jamesii*[3]	New Mexico	10

[1] 'Nordan,' 'Fairway,' Russian wildrye, alkali sacaton, sand dropseed, blue grama, and galleta were purchased. The source shown is the State where the species was grown. Squirreltail and penstemon were collected in Utah.

[2] A hybrid between an induced tetraploid form of *A. cristatum* and the tetraploid *A. desertorum*, developed by the USDA Agricultural Research Service at Logan, Utah.

[3] Galleta was not one of the species used in 1977 or 1978. it was planted in May 1980 as container-grown plugs.

mean plant height of transplanted plugs of the four warm-season grass species. In 1982 the same information was obtained for the warm-season species, plus data on yield as determined by the weight estimate method.

No supplemental water was applied to any of the above grass seedings or planting of grass plugs.

Shrub Establishment

Although fourwing saltbush, whitesage, shadscale, and Nevada ephedra had been used in the seed mixture sown on Persayo, Penoyer, and Castle Valley soils, we wanted to learn more about what species of shrubs could be established on the different kinds of soil materials present on the study area.

In April 1978 approximately two dozen species of container-grown shrubs were planted on sites of the Persayo, Penoyer, and Castle Valley soil series, and on a fourth site where the soil material consisted of a clayey, gypsiferous subsoil derived from shale (hereafter referred to as the shaley subsoil site). All except three of these species were members of the family Chenopodiaceae, and the group included three naturally occurring hybrids within the genus *Atriplex*. These plantings were made on both topsoil and subsoil on the Penoyer soil, but on topsoil only on Persayo and Castle Valley soils.

In April 1979 nearly all of the same species were planted on soil material derived from Blue Gate shale. This site had the topsoil removed, the subsoil ripped to a depth of 30 inches (76 cm) and releveled, and the topsoil replaced.

Additional plantings of container-grown stock were made in April of 1979 on Persayo and Castle Valley soils primarily to evaluate other natural and developed hybrids of *Atriplex*. These plantings were made on plots adjacent to the 1978 plantings.

Species were planted in plots 6 by 12 ft (1.8 by 3.6 m) in a randomized-block design, with four replications on each site. Each plot contained two rows of four plants, planted on a 36-inch (0.9 m) grid spacing.

Appendix figures 45 through 51 show field plot designs for the shrub evaluation plantings at Emery. Appendix table 41 lists the species planted on the several study sites, and the origin of each.

All planting stock used in these studies was grown in small containers (most in Spencer-Lemaire, "Rootrainers") in either the Forest Service greenhouse at Provo, Utah, or in the Brigham Young University greenhouse, also in Provo. At Brigham Young University, Dr. Howard Stutz worked under a cooperative research agreement[1] designed to develop new and improved strains of *Atriplex* for use on surface mine reclamation sites. Planting stock was usually 2 to 6 months old when planted at the field site. All plants were watered with 1 qt (0.95 liter) of water at the time of planting. On June 5 and July 20, 1 qt of supplemental water was applied to all plants of the 1978 plantings. The plants on the shaley subsoil site were also given that amount of water on June 29. All plants in two replications at each of the 1978 planting sites were given 2 qt (1.9 liter) of water on August 24 and September 12. The 1979 plantings were provided with supplemental water (1 qt each time) on 10 occasions at 2- to 3-week intervals during summer 1979 to aid establishment. No supplemental water was applied after the first growing season.

Information on some selected soil properties at each of the four major shrub planting sites is given in table 3.

We obtained data on the percent survival and the mean height and diameter of all shrub species in autumn 1978, spring and autumn 1979, autumn 1980, spring and autumn 1981, and autumn 1982.

Table 3.—Properties of soils at the shrub species evaluation sites, Emery coal field

Soil property	Persayo series	Penoyer series	Castle Valley series	Blue Gate shale	Shaley subsoil
Soil reaction (pH)	7.8	8.0	7.7	7.4	7.5
Conductivity (EC_e, mmhos/cm)	3.2	.5	3.8	2.9	5.7
Sodium adsorption ratio (SAR)	4.0	2.0	2.0	1.0	2.7
Cation exchange capacity	5.7	5.7	7.9	8.2	16.4
Saturation percentage	30.0	27.0	37.0	41.0	87.0
Percent moisture at					
0.1 atm	18.0	17.0	22.0	26.0	27.2
0.33 atm	10.0	9.0	14.0	19.0	19.8
15 atm	6.0	5.0	9.0	11.0	12.4
Percent sand	56.0	60.0	44.0	32.0	4.0
Percent silt	25.0	24.0	32.0	57.0	49.0
Percent clay	19.0	16.0	24.0	11.0	47.0
Textural class	SL	SL	L	SiL	SiC

Globemallow and Alkali Sacaton

Scarlet globemallow and alkali sacaton, a forb and a grass respectively, are native species on the Emery coal field. Globemallow is highly palatable to both livestock and deer. Although alkali sacaton is rather coarse and tough after curing, it is quite palatable during the growing season. Our study objective was to evaluate the degree of competition that previously established shrub species would pose for the survival and growth of scarlet globemallow and alkali sacaton on the several different soils present on the study area.

In April 1979, 2-month-old container-grown plants of globemallow and alkali sacaton were planted between the established shrubs on the shrub evaluation plots that had been planted in 1978. We used three replications of the shrub planting sites on Persayo, Penoyer, Castle Valley, shaley subsoil, and Blue Gate shale soils. On one replication, eight globemallow plants were put between the shrubs on each subplot. The second replication had eight sacaton plants on each subplot, and the third replication had four sacaton and four globemallow plants, in alternate fashion. Thus, the shrub species occupying each subplot was to provide competition for either eight globemallow plants, eight sacaton plants, or four of

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[1] Memorandum of Understanding, Contract No. 12-11-204-31, between Brigham Young University and Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

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each. Because of a shortage of globemallow planting stock, only sacaton was planted on the shrub plots located on shaley subsoil. The globemallow and sacaton plants were given 1 qt (0.95 liter) of water at the time of planting, and a similar amount at 2- to 3-week intervals throughout the first growing season.

In September 1980, and in May 1981 and 1982, data were obtained on the survival of the interplanted alkali sacaton and scarlet globemallow.

Native Pinyon and Juniper

Pinyon and Utah juniper trees occur at the higher elevations of the Emery coal field. Both species are slow growing, especially in their first several years of life. On occasion it may be desirable to reestablish some trees on reclaimed areas as rapidly as possible, either for esthetic reasons or to provide a measure of protective cover from the elements for livestock and wildlife.

In late April 1980 an end-loader developed by the Forest Service's Missoula, Mont., Equipment Development Center was used to determine the feasibility of lifting and transplanting pinyon and juniper trees 3 to 10 ft (1 to 3 m) tall. The large bucket of this equipment is 14 ft wide and 9.5 ft deep (4.3 m and 2.9 m). It was developed primarily to lift and transplant blankets of the sod-forming grass species.

Field crews lifted and transplanted 12 pinyon and 19 juniper trees onto a site immediately adjacent to the study area on Persayo soil; 25 pinyon and 19 junipers were lifted and moved 50 to 200 yards (46 to 183 m) on soils of the Penoyer series. On the Persayo site, the trees, with their attached pad of soil, were simply placed on the soil surface at their new location. However, on the Penoyer site, the bucket was used to excavate a spot of similar size and depth to that of the soil and root system mass that was to be received.

Survival of the transplanted trees was monitored in autumn 1980, 1981, and 1982.

Characterization of the Microclimate

In May 1979, a battery-powered (solar-charged) automatic data logger was installed at the Persayo site on the study area. The data logger monitored ambient air temperature 54 inches (137 cm) above the soil surface, soil temperature at depths of 2 and 8 inches (5 and 20 cm) on both the Persayo and shaley subsoil, and precipitation received by an unheated, tipping bucket rain gage. Data were recorded at hourly intervals on magnetic tape.

In addition, thermocouple psychrometers were placed in the soil at depths of 8 and 20 inches (20 and 51 cm) on the Persayo, Penoyer, Castle Valley, Blue Gate shale, and shaley subsoil sites. Soil water potential was monitored on the Blue Gate shale, Castle Valley, and shaley subsoil shrub evaluation sites by implanting the psychrometers at two locations on each site. On both the Persayo and Penoyer soils, psychrometers were placed at six locations—three within the cultipacked treatment and three within the gouged treatment. All psychrometers located on gouged areas were placed in the soil directly below the center of the small pit formed by the gouging action. The psychrometers were read approximately every 3 weeks from June 29 to October 17, 1979. In 1980 and 1981 they were read at monthly intervals from April through October.

RESULTS AND DISCUSSION

After 5 years, grasses and shrubs generally declined in frequency on the study plots. However, all but one species produced more herbage on Penoyer soil than on Persayo soil. Shrub survival was highest on Castle Valley soil. Detailed studies were made of globemallow, alkali sacaton, pinyon, and juniper. Precipitation varied from a drought year to above-average moisture, giving a spectrum of results over the 5-year study.

Site Preparation and Soil Amendments

In spring 1978, seedling emergence was good on all treatments on both the Persayo and Penoyer soils. This may have resulted from 50 percent greater than average winter precipitation, most of which came from January through March 1978. The growing season of 1978 was quite dry. Total precipitation received in the area was only 40 percent of average for the months of April through October, with every month showing less than average precipitation. One storm, in late July, may have been effective in sustaining the young grasses and shrubs; 0.49 inch (12.5 mm) of rainfall was recorded at a gage 1 mile (1.6 km) from the study site.

At the end of the first growing season, frequency of both grasses and shrubs was higher on cultipacked and harrowed areas than on gouged areas of both soil types (table 4). In the case of grasses, this was especially noticeable on the somewhat sandier Penoyer soil.

Table 4.—Mean percent frequency of grasses and shrubs by seedbed preparation treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1978	1979	1980	1981	1982
Persayo soil					
Grasses					
Gouged	70	45	64	59	65
Cultipacked	82	64	78	69	70
Harrowed	77	68	68	78	56
Shrubs					
Gouged	41	28	[2]31	[2]25	[2]23
Cultipacked	44	39	37	33	27
Harrowed	53	54	37	42	55
Penoyer soil					
Grasses					
Gouged	45	[1]41	45	45	46
Cultipacked	70	51	64	59	68
Harrowed	88	72	84	78	73
Shrubs					
Gouged	[3]22	14	6	11	9
Cultipacked	19	8	3	5	5
Harrowed	56	32	28	20	16

[1] Frequency was not obtained for all species of grasses (as a class) on Penoyer soil in 1979. Data for 1979 are for crested wheatgrass only.

[2] Frequency was not obtained for all shrubs (as a class) in 1980, 1981, and 1982 on Persayo soil. Data for these 3 years represent the sum of frequency values of all four shrub species.

[3] Frequency of all shrubs (as a class) on Penoyer soil was only recorded in 1978. Data for other years represent the sum of frequency values of all four shrub species.

Harrowing lightly, immediately after broadcast seeding, was clearly the most favorable of the three surface treatments for shrub establishment (fig. 5). Even after 5 years, shrub frequency was still highest on the harrowed areas of both the Persayo and Penoyer soils.

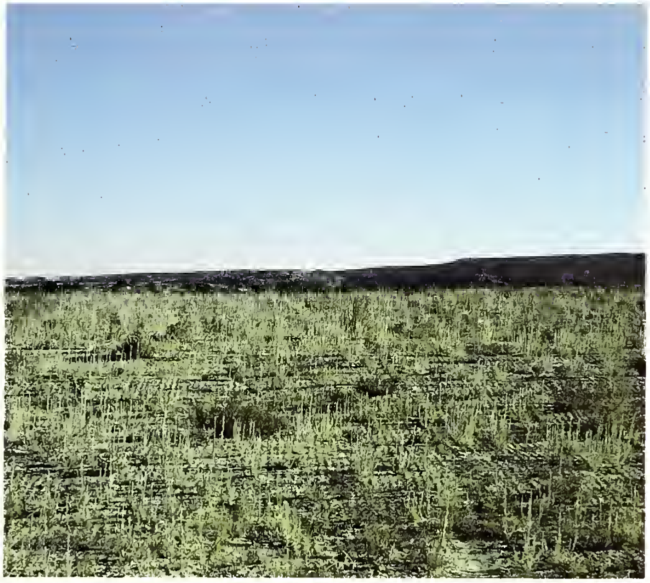


Figure 5.—Excellent establishment of Ceratoides lanata *and* Atriplex confertifolia *was obtained on area of Persayo and Penoyer soils when broadcast-seeding was followed by light harrowing. October 1978.*

Seedling establishment resulting from lightly harrowing Persayo and Penoyer soils after broadcasting seed was better than the results from the cultipacking or gouging treatments. In the gouging procedure, the seed was dispensed from the hopper and fell onto the newly gouged soil surface, where seed was only likely to be covered by soil in the gouged pit. Little seedling establishment occurred on the ridges between pits. Cultipacking, which in this case was done after seed was broadcast, served to press the seed into the surface of the loose soil. However, it left a smooth surface, where any seed not anchored in the soil was subject to movement by wind. Winterfat, which has a light, feathery utricle, was noticeably more abundant on the harrowed areas than on gouged or cultipacked areas (fig. 5).

On Persayo soil, after 2 years, mean yields were higher on gouged areas than on harrowed or cultipacked areas, and with the exception of 1981, remained slightly higher. However, statistical analyses of the 1982 data gave no evidence to support a claim of differences between treatments. On Penoyer soil, yields on gouged areas were equal to those on harrowed and cultipacked areas by the third year, and appeared to be slightly higher after 5 years. Shrub yield seemed to be higher, initially, on harrowed areas, but the differences between harrowed, gouged, and cultipacked areas appear to be diminishing with time (table 5).

Table 5.—Mean yield (lb/acre, air – dry) of grasses and shrubs by seedbed preparation treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1979	1980	1981	1982
Persayo soil				
Grasses				
Gouged	130	908	278	338
Cultipacked	88	813	292	223
Harrowed	91	644	241	265
Shrubs				
Gouged	[1]—	358	73	82
Cultipacked	—	343	68	71
Harrowed	—	398	55	130
Penoyer soil				
Grasses				
Gouged	442	1,700	711	616
Cultipacked	508	1,716	616	555
Harrowed	768	1,685	428	455
Shrubs				
Gouged	85	144	43	122
Cultipacked	60	41	25	21
Harrowed	203	294	25	41

[1] No yield data were obtained in 1979.

The primary benefit from gouging is the retention of precipitation (both rain and snow) on the treated area, rather than losing rain by overland flow and snow by being blown from a bare, level soil surface. In an arid region, plants benefit greatly from relatively small increases in available soil moisture. At Emery, the pits formed by gouging did serve to retain precipitation, as reflected by higher soil water potential measurements from psychrometers under gouged pits. Pits formed by gouging on the study areas were still fairly stable after 5 years.

The establishment of grasses was enhanced by the addition of a hay amendment to the soil (table 6). Conversely, where grasses established well, shrub establishment was inhibited. However, by the fifth year percent frequency of grasses on the Penoyer soil was essentially the same on hay-amended, compost-amended, and control areas, although shrub frequency was still lowest on hay-amended areas. On Persayo soil, differences in percent frequency of grasses diminished with time (table 6), whereas shrub frequency remained highest on nonamended areas. Frequency of occurrence was not only higher on the hay-amended portions of the 6-acre (2.4-ha) and 4-acre (1.6-ha) areas, where a seed mixture was sown, but also on the small plots where individual species of grasses were tested. Although yields were generally greater on hay-amended areas in the second and third growing seasons (except on the main area of Penoyer soil in 1979), only in the latter year were differences statistically significant (table 7). By the fifth year, on both soil types, yield of both grasses and shrubs were similar regardless of amendment treatments.

Table 6.—Mean percent frequency of grasses and shrubs by soil amendment treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1978	1979	1980	1981	1982
Persayo soil					
Grasses					
Hay	85	66	81	70	71
Compost	68	36	65	56	65
Control	70	54	63	65	62
Shrubs					
Hay	39	30	[2]29	[2]25	[2]16
Compost	54	28	42	30	21
Control	46	46	38	37	45
Penoyer soil					
Grasses					
Hay	73	[1]58	68	61	62
Compost	63	52	62	62	64
Control	66	53	63	59	61
Shrubs					
Hay	[3]26	5	3	3	4
Compost	32	15	13	15	7
Control	38	34	21	19	18

[1] Frequency was not obtained for all species of grasses (as a class) on Penoyer soil in 1979. Data for 1979 are for crested wheatgrass only.

[2] Frequency was not obtained for all shrubs (as a class) in 1980, 1981, and 1982 on Persayo soil. Data for these 3 years represent the sum of frequency values of all four shrub species.

[3] Frequency of all shrubs (as a class) on Penoyer soil was only recorded in 1978. Data for other years represent the sum of frequency values of all four shrub species.

Of the four shrub species used, winterfat (*Ceratoides lanata* [Pursh] J. T. Howell) occurred most frequently in the young stand, constituting 55 percent of the shrub population on both soil types. Shadscale made up 35 percent of the first-year shrub stand on Penoyer soil, followed by fourwing saltbush and Nevada ephedra (*Ephedra nevadensis* Wats.) with 5 percent each. On Persayo soil, winterfat was followed in percent composition of the shrub population by shadscale (17 percent), Nevada ephedra (14 percent), and fourwing saltbush (13 percent). After 5 years, shadscale was the most frequent shrub on Persayo soil, whereas on Penoyer soil, winterfat, shadscale, and fourwing saltbush were nearly equal in frequency. Fourwing saltbush and winterfat both appear to grow more vigorously on Penoyer soils than on Persayo soils. Nevada ephedra did not exhibit good growth on either soil, at least not in competition with grasses.

Table 7.—Mean yield (lb/acre, air-dry) of grasses and shrubs by soil amendment treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1979	1980	1981	1982
Persayo soil				
Grasses				
Hay	114	1,105	293	266
Compost	161	796	297	337
Control	81	566	259	272
Shrubs				
Hay	[1]—	278	53	47
Compost	—	502	120	77
Control	—	388	67	117
Penoyer soil				
Grasses				
Hay	517	2,198	524	551
Compost	595	1,739	590	548
Control	607	1,164	641	527
Shrubs				
Hay	27	96	17	78
Compost	88	146	34	46
Control	233	236	43	59

[1] No yield data were obtained in 1979.

During the 5 years of study both grasses and shrubs declined in percent frequency (table 4). However, crested wheatgrass maintained its dominant position on both soils and decreased little in percent frequency. Russian wildrye remained the second highest grass species in terms of percent frequency, on both soils, but decreased nearly 50 percent in frequency over the 5 years. This species is favored by good early spring moisture and was especially vigorous on the deeper, Penoyer soil area in 1982.

Soil Amendments and Herbaceous Species

Alfalfa hay and composted conifer bark were also tested on small plots as soil amendments with 10 species of grass and one forb. All species were established on both topsoil and subsoil of the Persayo and Penoyer soil series.

In spring 1978 seedling establishment of the six "cool season" grass species was good. However, the four "warm season" grasses failed to germinate, and in May 1980 were established from container-grown planting stock. The lone forb, Palmer penstemon, germinated sporadically but by the second year had established quite well on several plots.

In the first growing season, percent frequency and seedling density of the cool season grasses were greatest on hay-amended plots of the topsoil of both Persayo and Penoyer soils, although the differences may not have been statistically significant. On subsoil plots, little difference existed between hay-amended and control plots. The addition of a composted bark soil amendment seemed to decrease grass establishment in every case. Although the overall mean percent frequency of young plants was similar on topsoils and subsoils, the former produced taller plants than the latter.

In the second year, data analyses indicated that plant frequency was still significantly lower on compost-amended plots of both Persayo and Penoyer soils. On Persayo soil, overall yield of grass was significantly higher on topsoil than on subsoil, but there was no difference between yields on Penoyer topsoil and subsoil. Yields were not significantly different according to soil amendment treatment on either Persayo or Penoyer soil.

In the third growing season (1980) yields were significantly higher on hay-amended plots than on compost-amended or control plots (table 8). In 1980, a year of exceptionally high soil moisture in the early part of the growing season, grasses on hay-amended plots were darker green in color than grasses on compost-amended or control plots. Laboratory analyses of herbage samples showed that grasses growing on hay-amended plots contained 1.3 to 3 times as much nitrogen as grasses growing on the other treatment plots. The darker green color on hay-amended areas was apparent on both the Persayo and Penoyer soils, and also on the larger areas of both soils where the seed mixture had been used (figs. 6 and 7). The color was still apparent in the fifth year.

Table 8.—Combined yield (lb/acre, air-dry) of six species of cool season grasses by soil amendment treatment on Persayo and Penoyer soils, Emery coal field

Soil and year	Treatment Hay	Compost	Control
Persayo soil			
1979	572	336	358
1980	646	435	399
1981	309	308	300
1982	232	203	284
Penoyer soil			
1979	303	119	242
1980	873	536	792
1981	363	331	378
1982	568	375	470

Percent frequency decreased on both Persayo and Penoyer soils in the fourth year, 1981, which was a dry growing season (table 5). In 1982, percent frequency rebounded to 1980 levels on the Penoyer soil but remained somewhat lower than the 1980 level on the Persayo soil.

Yields also decreased sharply in 1981 on all treatments of both soil series. In 1982, yields made some recovery on Penoyer soil but declined even further on Persayo soil (table 8).

Of the 10 species evaluated on the small plots, the three wheatgrasses, Russian wildrye, and squirreltail grass exhibited good seedling establishment on Persayo soil. On the Penoyer soil the three wheatgrasses were highest in percent frequency the first year. As previously mentioned, none of the three warm season grasses showed sufficient seedling emergence to warrant continued observation.

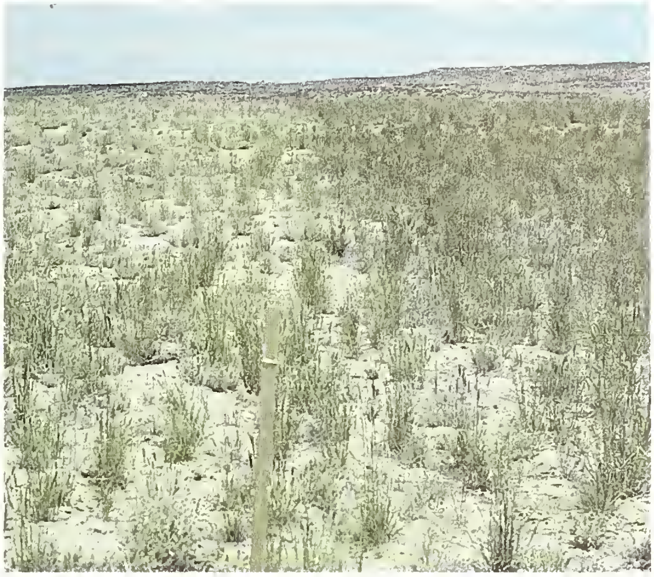


Figure 6.—Seeded grasses were more vigorous and were darker green in color in the third growing season on areas where alfalfa hay had been rotovated into the top 8 inches of soil. June 1980.

From the second through the fifth years, the induced hybrid crested wheatgrass and Russian wildrye each exhibited a smaller decrease in percent frequency than the other cool season grasses on Persayo soil. On Penoyer soil during the same time period, Indian ricegrass changed from lowest to highest in percent frequency while squirreltail grass steadily decreased (table 9).

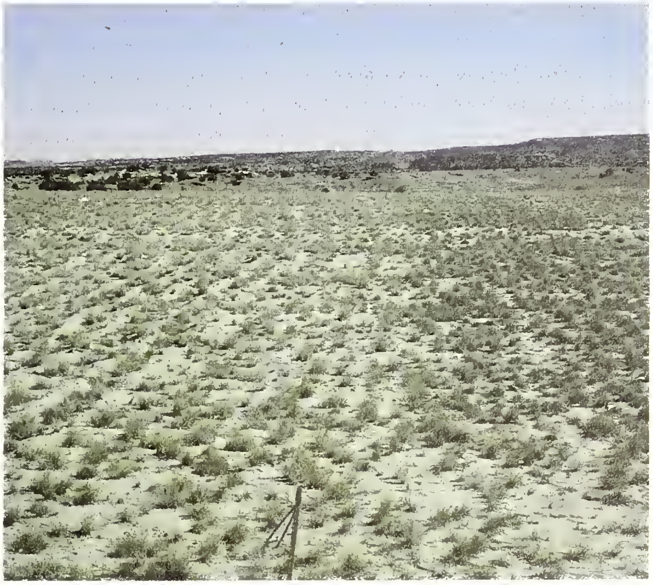


Figure 7.—Photo taken in September 1981 from same point as shown in Figure 6. Seeded grasses "greened up" following 2.64 inches (6.7 cm) of rain on the area where alfalfa hay soil amendment had been used in autumn 1977.

Table 9.—Percent frequency of six cool season grasses on small plots of Persayo and Penoyer soil, Emery coal field

Grass	1978	1979	1980	1981	1982
Persayo soil					
'Nordan' crested wheatgrass	89	81	68	59	59
'Fairway' crested wheatgrass	95	94	76	69	72
Crested wheatgrass hybrid	94	95	84	80	80
Russian wildrye	96	91	85	80	77
Indian ricegrass	77	49	45	32	35
Squirreltail grass	91	86	72	60	65
Penoyer soil					
'Nordan' crested wheatgrass	81	87	74	67	72
'Fairway' crested wheatgrass	89	88	63	55	60
Crested wheatgrass hybrid	92	88	68	55	70
Russian wildrye	68	84	66	55	67
Indian ricegrass	53	70	67	64	78
Squirreltail grass	62	72	35	29	32

Yield of the individual grass species reached a peak in the third growing season, except for Indian ricegrass, which has shown an increase with time (table 10). By the fifth year, Indian ricegrass had become the highest yielding species on both Persayo and Penoyer soils (fig. 8). Beginning with the third year, all species except squirreltail grass produced more herbage on Penoyer soil than on Persayo soil. Mean yields were greater on Penoyer soil in 1982 than in 1981 (except for squirreltail grass), but yields of all species except Russian wildrye continued to decline on Persayo soil. The growing season of 1982 was a good one for Russian wildrye because of good early season soil moisture, which the early developing wildrye was able to take advantage of.

Table 10.—Mean yield (lb/acre, air-dry) of six cool season grasses on Persayo and Penoyer soils, Emery coal field

Grass	1979	1980	1981	1982
Persayo soil				
'Nordan' crested wheatgrass	510	666	310	245
'Fairway' crested wheatgrass	568	549	302	193
Crested wheatgrass hybrid	675	724	289	226
Russian wildrye	350	447	250	282
Indian ricegrass	104	193	394	336
Squirreltail grass	327	380	290	155
Penoyer soil				
'Nordan' crested wheatgrass	360	1,078	382	491
'Fairway' crested wheatgrass	229	882	418	455
Crested wheatgrass hybrid	498	1,051	464	532
Russian wildrye	109	601	295	468
Indian ricegrass	58	550	494	790
Squirreltail grass	73	252	93	89

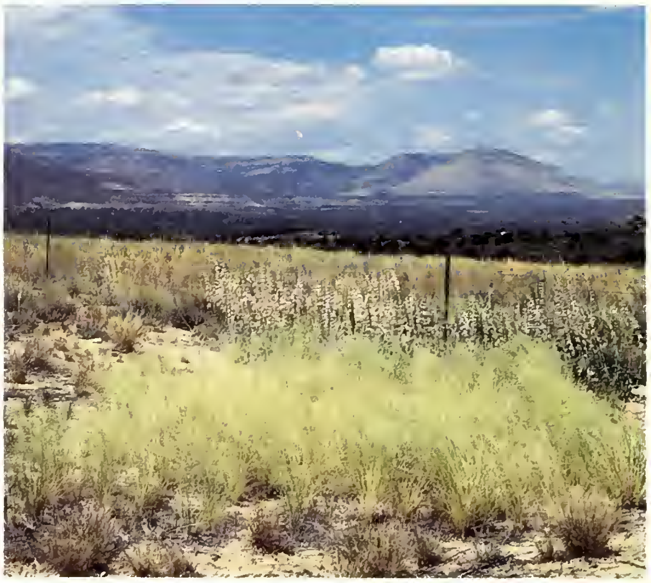


Figure 8.—An excellent growth of Oryzopsis hymenoides *on the small test plots of individual species on Penoyer soil. June 1982.*

Warm Season Grasses and Palmer Penstemon

Percent survival of the four species of warm season grasses, established on the small plots in May 1980 by planting container-grown plugs, is shown in table 11. Only where the grass plugs were planted adjacent to plots of well-established cool season grasses was mortality evident in the first year, 1980. Alkali sacaton was the most vigorous of the four species on both soil series, although blue grama also showed good vigor on the Penoyer soil. All species on Penoyer soil were subjected to severe competition from the annual weed *Kochia scoparia* (L.) Schrad. (summer cypress). At times, surviving plants were difficult to locate in 1981. The hay and composted bark soil amendments that had been applied at the beginning of the study (1977) had no effect on survival of these warm season grasses.

Table 11.—Percent survival of four warm season grasses established from plug transplants, Emery coal field

Grass	1981	1982
Persayo soil		
Blue grama	94	90
Alkali sacaton	94	91
Sand dropseed	91	73
Galleta	86	79
Penoyer soil		
Blue grama	86	81
Alkali sacaton	76	74
Sand dropseed	68	72
Galleta	66	57

Yield data obtained in 1982 by the weight-estimate method indicated that alkali sacaton produced the greatest amount of herbage on both soil series (table 12). However, this species should be expected to yield more than blue grama and galleta because the latter two are by nature much smaller in stature in the Emery area. Three of the four species showed higher yields on Penoyer soil than on Persayo soil. Yields of galleta grass were similar on the two soils.

Table 12.—Mean yield (lb/acre, air-dry) of four warm season grasses on two soil series in the third year, Emery coal field

Series	Alkali sacaton	Blue grama	Galleta	Sand dropseed
Persayo soil	228	118	158	105
Penoyer soil	293	214	164	241

Palmer penstemon, which had been seeded in autumn 1977 on plots of both Persayo and Penoyer soil, established well on several plots after germinating in spring 1979. It survived well and reproduced from seed through the next 4 years (fig. 9).

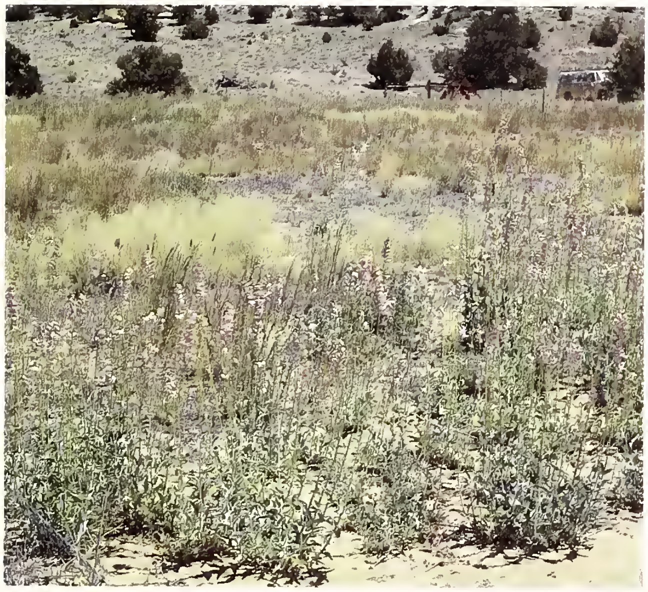


Figure 9.—Excellent plot of Penstemon palmeri *established by broadcast seeding on Penoyer soil in spring 1978. Photo taken July 9, 1982.*

Seeding of Ripped Castle Valley Topsoil

No data were taken on the 2 acres (0.8 ha) of ripped Castle Valley topsoil. However, after 5 years the portion of the area where the topsoil was not removed supported a good mixture of grass and shrubs, mostly shadscale (fig. 10).

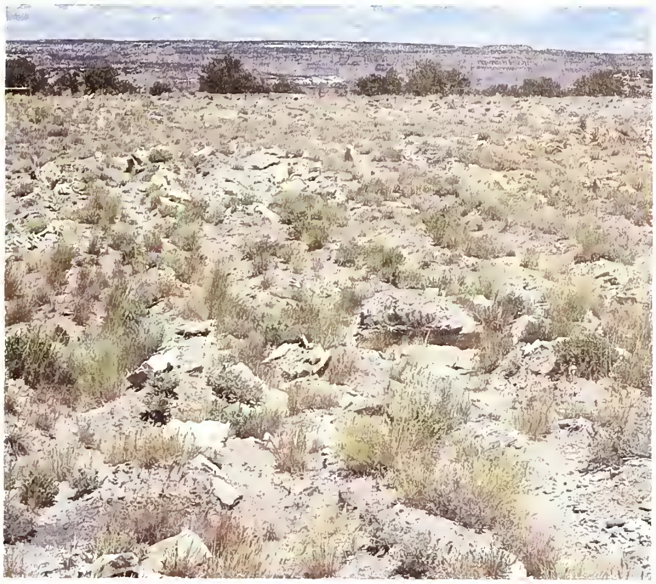


Figure 10.—A good stand of perennial grasses and shrubs in the fifth year following deep ripping and broadcast seeding on Castle Valley soil, Emery study area. July 9, 1982.

In sharp contrast, after 5 years the area from which the top foot of topsoil was removed supported an extremely sparse stand of seeded shrubs and grasses (fig. 11).

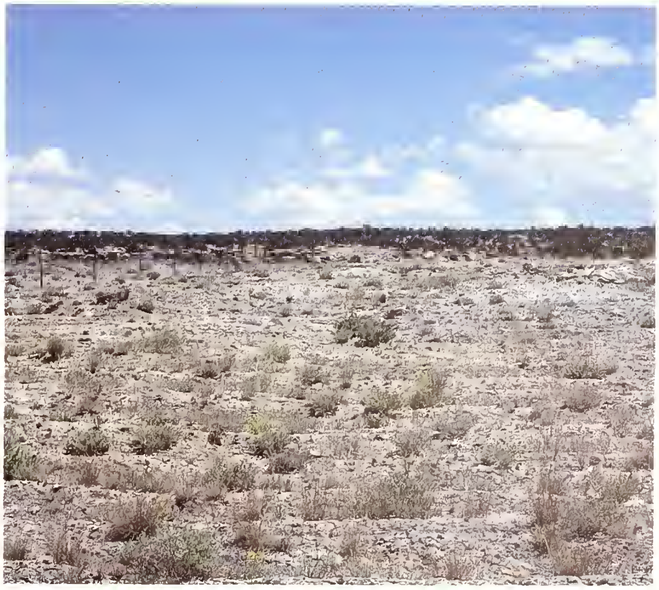


Figure 11.—A poor stand of perennial grasses and shrubs in the fifth year following removal of 12 inches of topsoil, ripping to a depth of 32 inches, and broadcast seeding on Castle Valley soil at the Emery study area. July 9, 1982.

Shrub Establishment

Container-grown shrubs survived well and made excellent growth during the first growing season (1978) on all soils except the shaley subsoil. Supplemental water increased plant survival only on shaley subsoil. Average height of plants at the end of this season was 3 inches (7.6 cm) greater on Castle Valley soil than on the other three sites. Plants on shaley subsoil plots averaged only half the growth of plants on Persayo and Penoyer soils.

Table 13 shows the mean percent survival of shrubs planted on five sites after 5 years. The planting on the Blue Gate shale site was made in 1979.

Over the 5 years of observations, overall survival was highest on Castle Valley soil and lowest on Persayo soil. The reason for the higher survival on Castle Valley soil is not definitely known but could be due to either a slightly greater clay content than that of the other soils (except for the shaley subsoil) or to the fact that the plots of Castle Valley soil were constructed by spreading a layer of this topsoil to a depth of between 3 and 4 ft (0.9 and 1.2 m) deep.

Although first-year mortality was high on the shaley subsoil, few plants succumbed in the subsequent 4 years. Plants on this site faced virtually no competition, because invasion by native species was extremely sparse (fig. 12). On the other hand, shrubs on the Persayo soil faced considerable competition from Russian wildrye, crested wheatgrass, and some shadscale, all of which became established from seed blown onto the area when the adjacent 6-acre (2.4-ha) study area was broadcast seeded (fig. 13).

Atriplex navajoensis was the only shrub species to exhibit lack of winter hardiness, failing completely on three of the four sites on which it was planted.

The 1979 growing season was extremely dry. Many shrub species showed signs of moisture stress by September, and mortality was evident by early spring 1980.

Most species showed little increase in size after the second year. Because all except three of the species tested were chenopods, they will most likely grow rapidly during the first couple of years to a size near maximum for the environment of the Emery coal field.

Table 13.—Mean percent survival of shrub species on five soil types at the end of the fifth growing season, Emery coal field

	Soil types					
Species symbol[1]	Shaley subsoil	Persayo topsoil	Penoyer topsoil	Castle Valley topsoil	Blue Gate shale topsoil	Mean for all soils
ARNO	44	70	81	62	np	64
ATAP	38	25	44	38	81	45
ATBO	78	75	78	94	78	81
ATCA	81	19	66	69	94	66
ATCA x ATCU	96	31	88	88	78	76
ATCA x ATID	59	np	69	np	47	58
ATCA x ATTR	62	np	38	100	34	58
ATID	np	50	np	91	72	71
ATOB	75	84	84	100	75	84
ATRO	25	38	0	95	12	34
ATTO	50	19	44	65	np	44
ATTR 1	62	56	78	100	97	79
ATTR 2	78	25	84	88	84	72
ATNA	0	0	0	56	np	14
CAMO	81	84	50	74	97	77
CELA	66	91	84	97	84	84
CEPA	72	np	91	100	94	89
EPNE	56	53	97	91	np	74
ERCO	62	22	3	np	np	29
GRSP	44	56	72	92	np	66
KOPR 4	96	84	75	88	97	88
KOPR 7	100	np	94	np	100	98
KOPR 9	100	np	100	np	np	100
KOPR 11	np	97	np	97	np	97
KOPR 12	np	94	np	100	100	98
Mean	68	57	69	85	78	70

[1] See appendix table 41 for list of species and original source, if known. See appendix table 69 for plant symbol key.
np = species not planted on this site.

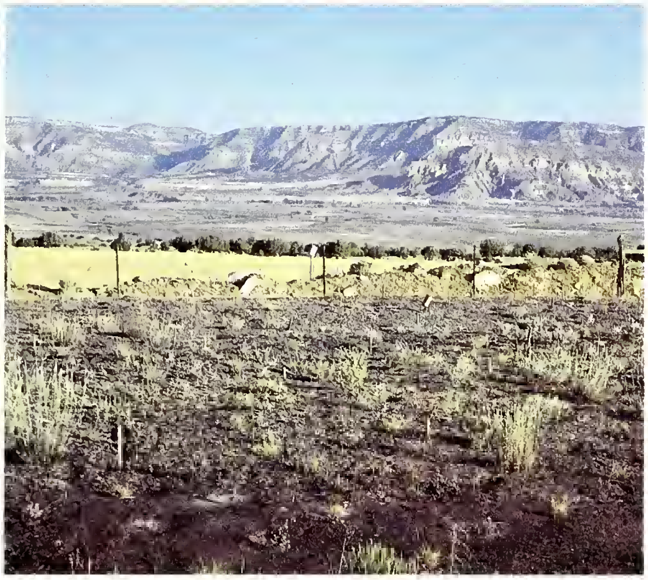


Figure 12.—Shrub evaluation planting on shaley subsoil material at the Emery study area. Note the absence of any invading plant competition. August 1980.

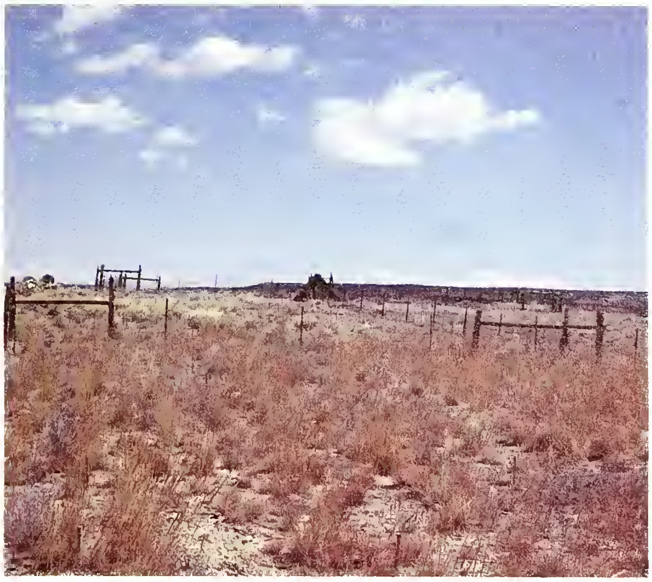


Figure 13.—Shrub evaluation planting on Persayo topsoil at the Emery study area. Severe competition from Russian wildrye and crested wheatgrass exists on the area. July 1982.

The three nonchenopod species (ephedra, black sagebrush, and corymbed eriogonum) have shown additional increase in size each year, although all have grown slowly. Table 14 shows mean height and diameter of all species tested at the end of 5 years. Most species were most vigorous on the Penoyer soil and exhibited slowest growth on shaley subsoil and Blue Gate shale soils.

The criterion of size attained does not always reveal which shrub species are well adapted to a certain soil type. Corymbed eriogonum occurs primarily on shaley

Table 14.—Mean height and mean canopy diameter (inches) of shrub species after 5 years on five soil types, Emery coal field

Species symbol[1]	**Shaley subsoil**		**Persayo topsoil**		**Penoyer topsoil**		**Castle Valley topsoil**		**Blue Gate shale topsoil**	
	Ht.	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*
ARNO	4	6	8	8	12	15	7	8	—np—	
ATAP	5	8	16	24	9	14	7	11	4	7
ATBO	8	12	10	15	16	23	14	20	7	9
ATCA	11	14	18	19	16	21	12	17	10	12
ATCA x ATCU	12	14	12	17	22	27	12	17	5	7
ATCA x ATID	5	7	—np—		11	15	—np—		5	7
ATCA x ATTR	6	10	—np—		10	14	10	16	3	6
ATID	—np—		8	15	—np—		10	16	6	8
ATOB	7	9	11	12	7	9	10	18	5	7
ATRO	3	4	4	7	0	0	6	10	5	5
ATTO	5	6	12	15	7	11	6	12	—np—	
ATTR 1	4	9	9	14	7	12	9	16	5	10
ATTR 2	8	12	9	11	10	13	10	16	5	9
ATNA	0	0	0	0	0	0	10	15	—np—	
CAMO	4	13	7	10	11	15	11	13	4	12
CELA	6	6	9	11	12	16	11	15	9	11
CEPA	6	7	—np—		16	24	9	11	10	10
EPNE	5	6	7	7	11	14	9	8	—np—	
ERCO	9	12	8	13	13	22	—np—		—np—	
GRSP	4	5	9	10	10	14	10	14	—np—	
KOPR 4	6	14	20	19	18	24	19	21	7	16
KOPR 7	6	15	—np—		18	22	—np—		6	14
KOPR 9	5	14	—np—		19	26	—np—		—np—	
KOPR 11	—np—		17	16	—np—		14	16	—np—	
KOPR 12	—np—		17	16	—np—		17	20	6	12
Mean	6	10	11	14	13	18	11	15	6	10

[1] See appendix table 41 for species list and original source, if known. See appendix table 69 for plant symbol key.
np = not planted on this site.

soil of high clay content on the Emery coal field. Indeed, survival of planted eriogonum was much higher on the shaley subsoil than on either Persayo or Penoyer soil. However, the few plants that survived on the sandy loam, Penoyer soil have grown well. *Atriplex tridentata* appears to thrive somewhat better on Persayo soil than on Penoyer soil. Black sagebrush does not appear well adapted to shaley, clayey soil.

Mediterranean camphorfume, prostrate summer-cypress, and trident saltbush grew well on all soils on which they were planted (figs. 14 and 15). Broadscale saltbush performed nearly as well on all soils. Winterfat seems well adapted to Penoyer soil (fig. 16) and only slightly less adapted to Castle Valley and Blue Gate soils. Other species that should prove useful on particular soils are fourwing saltbush, plumed whitesage, Bonneville saltbush, black sagebrush, and hybrids of fourwing saltbush with cuneate saltbush (*Atriplex cuneata* A. Nels.) (fig. 17) and with trident saltbush.

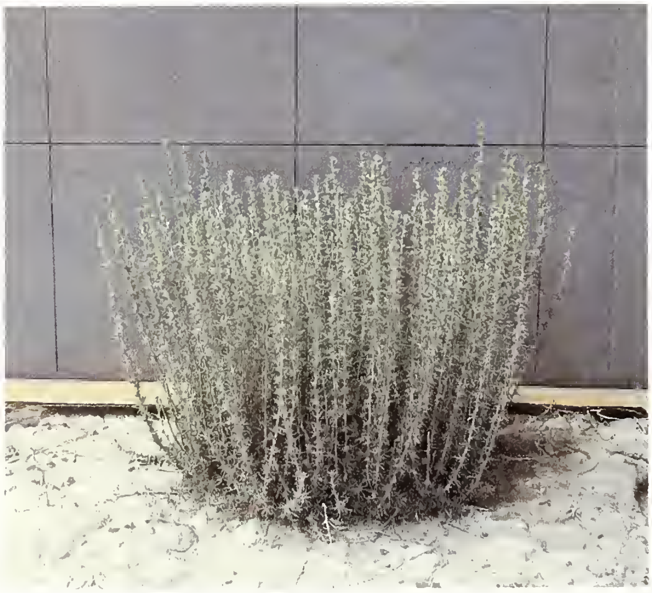


Figure 14.—Good plant of Camphorosma monspeliaca, *an introduction from the U.S.S.R., growing on Blue Gate shale soil material. The plant is in the fourth growing season. August 1982.*

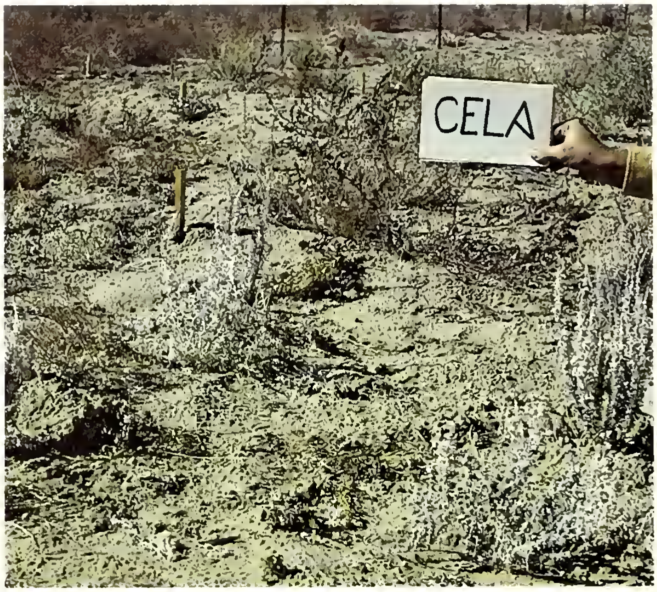


Figure 16.—Excellent plants of Ceratoides lanata *at the end of the first growing season on Penoyer topsoil. October 1978.*

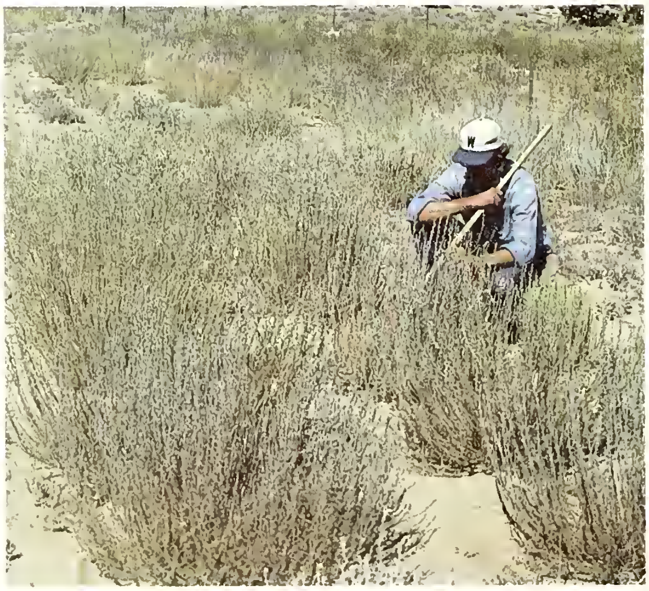


Figure 15.—Excellent plants of Kochia prostrata, *an introduction from the U.S.S.R., growing on Penoyer topsoil. Plants are in the second growing season. August 1979.*

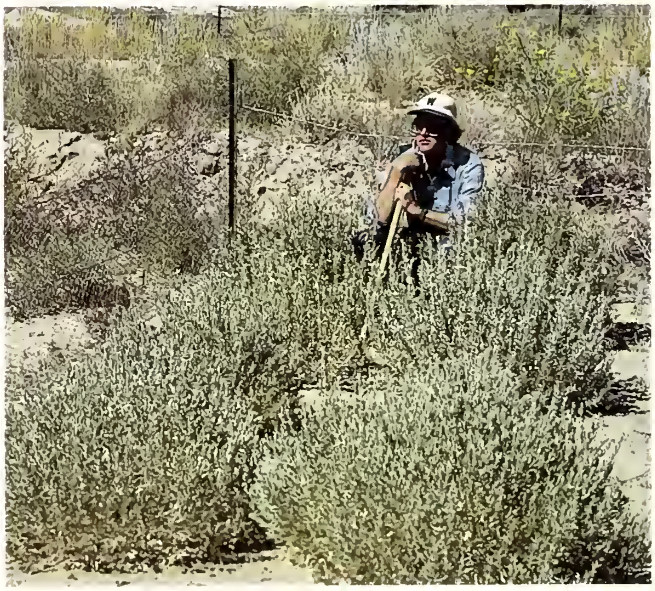


Figure 17.—Excellent growth of Atriplex canescens *x* Atriplex cuneata *hybrid in the second growing season on Penoyer topsoil. August 1979.*

Table 15.—Mean percent survival of shrub species on Persayo and Castle Valley soils after each of the first four growing seasons, Emery coal field

Species symbol[1]	Persayo soil				Castle Valley soil			
	1979	1980	1981	1982	1979	1980	1981	1982
ATBO x ATTR	98	97	94	94	100	100	100	100
ATCA (Yuma)	94	9	3	0	100	41	41	41
ATCA (Jericho)	94	50	44	22	94	44	25	12
ATCA x ATCO x ATCA	88	53	34	31	90	84	78	72
ATCA x ATOB	100	78	78	78	100	88	88	88
ATCA x ATID	100	94	88	88	np	—	—	—
ATCA x ATTR	98	69	53	50	98	88	88	88
ATCU x ATCO	np	—	—	—	78	67	67	63
ATFA	75	0	—	—	90	88	84	81
ATID	np	—	—	—	100	100	94	94
ATLA	100	84	75	75	100	100	100	100
ATRO	88	62	31	31	np	—	—	—
CEPA	100	100	94	91	np	—	—	—

[1] See appendix table 41 for scientific names and geographic source. See appendix table 69 for plant symbol key.
np = not planted on this site.

1979 Plantings

Supplemental watering on 10 occasions during the first growing season (1 qt or 1 liter/plant) resulted in excellent survival of most *Atriplex* accessions that year (table 15). Seven of eight accessions common to both the Castle Valley and Persayo plots showed higher survival on the Castle Valley soil after 4 years. Although several of these saltbush species and hybrids survived reasonably well, especially on the Castle Valley soil, growth of most has been quite slow (table 16). After 4 years, only the hybrids of *Atriplex canescens* with *Atriplex idahoensis* (the latter an undescribed taxon) and *Atriplex bonnevillensis* with *Atriplex tridentata* show promise of being useful plants on these soils. However, continued observations for a few more years should be made before final judgment is passed. The two accessions that seem least adapted on these sites are fourwing saltbush from Yuma, Ariz., and the gigas accession of fourwing saltbush from sand dunes near Jericho, Utah.

Table 16.—Mean height and crown diameter (inches) of shrub species on Persayo and Castle Valley soils after 4 years, Emery coal field

Species symbol[1]	Persayo soil		Castle Valley soil	
	Height	Diameter	Height	Diameter
ATBO x ATTR	8	11	10	14
ATCA (Yuma)	ns	ns	6	7
ATCA (Jericho)	7	5	8	4
ATCA x ATCO x ATCA	4	9	7	8
ATCA x ATOB	4	8	4	6
ATCA x ATID	8	15	np	np
ATCA x ATTR	6	9	4	6
ATCU x ATCO	np	np	2	5
ATFA	ns	ns	6	8
ATID	np	np	8	9
ATLA	5	6	6	7
ATRO	2	2	np	np
CEPA	8	11	np	np
Means	6	8	6	7

[1] See appendix table 41 for scientific names and geographic source. See appendix table 69 for plant symbol key.
np = not planted on this site.
ns = no survival of this species.

Globemallow and Alkali Sacaton

The addition of approximately 1 qt (0.95 liter) of supplemental water to each plant on eight occasions during the first growing season was sufficient to obtain excellent first-year survival of globemallow and alkali sacaton planted between established shrubs. Initial survival of sacaton was highest on shaley subsoil. Excellent survival on this clayey soil material may be explained by its high moisture-holding capacity and a minimum of competition with the established shrubs (shrubs on this soil have grown slowly). After 4 years, survival and vigor of sacaton remained best on the shaley subsoil and poorest on Persayo soil (table 17).

Table 17.—Survival of alkali sacaton and four accessions of globemallow on different soil types in fifth growing season, when interplanted with established shrubs, Emery coal field

Soil type	Alkali sacaton	Globemallow accessions			
		Gunnison	D.E.R.[1]	Alton	Ouray
Blue Gate topsoil	75	39	27	57	[2]np
Penoyer topsoil	92	82	85	72	65
Persayo topsoil	65	43	47	56	29
Castle Valley topsoil	68	58	57	35	np
Shaley subsoil	99	np	np	np	np
Mean		56	54	55	47

[1] D.E.R. = Desert Experimental Range, Millard County, Utah.
[2] np = not planted on this soil.

By early summer of the fifth growing season, 1983, globemallow survival seemed affected more by site than by the species of shrub growing near it. Survival of globemallow was highest on the Penoyer soil type, and lowest on the Blue Gate soil (table 17). There was little difference in mean survival of globemallow accessions across all sites, although soil type seemed to influence survival of the four accessions.

The species of shrub with which globemallow had to compete had relatively little effect on globemallow survival except for the severe competition of prostrate summercypress. In competition with five accessions of summercypress, globemallow averaged 30 percent survival (range of 20 to 38 percent), whereas in competition with 20 other shrub species, globemallow averaged 60 percent survival (range of 42 to 78 percent).

All four accessions of globemallow exhibited some vigorous individuals on each of the sites on which they were planted. Because plant size can be largely determined by genetic characteristics, it is difficult to compare the relative sizes of the globemallow accessions on the Emery planting sites. However, plants of the Ouray source (Uintah County) were the smallest in stature among the accessions planted on Persayo and Penoyer soils (table 18).

Prostrate summercypress provided severe competition for both alkali sacaton and globemallow, not only from the original eight summercypress plants on each plot, but also from large numbers of small, new plants of summercypress resulting from seed dispersal.

Table 18.—Mean size (inches) of four accessions of globemallow on each of four soil types in the fifth growing season, Emery coal field

Accession	Soil type							
	Penoyer		Castle Valley		Blue Gate		Persayo	
	Ht.	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*
Gunnison	12.0	9.4	11.8	7.7	10.4	8.0	6.3	5.3
D.E.R.[1]	12.6	12.5	11.8	10.3	7.7	6.2	5.9	4.5
Alton	13.2	12.6	8.9	7.8	10.5	10.2	6.2	4.4
Ouray	10.3	12.0	[2]np		np		5.3	3.4

[1] D.E.R. = Desert Experimental Range, Millard County, Utah.
[2] np = not planted on this soil.

Transplanting Local Pinyon and Juniper

In late April 1980, 19 Utah juniper and 12 pinyon trees were lifted and transplanted to a site near the Persayo-soil study area; 25 pinyons and 19 junipers were transplanted at the Penoyer-soil study area (fig. 18). Transplanted pinyons ranged from 1 to 11 ft (0.3 to 3.4 m) in height, with crown diameters from 1 to 10 ft (0.3 to 3 m). Transplanted junipers ranged from 1.5 to 9 ft (0.5 to 2.7 m) in height and from 1.5 to 10 ft (0.5 to 3 m) in crown diameter. A layer of soil 1.5 to 2.5 ft (0.5 to 0.8 m) deep was excavated with each tree (7 to 11.6 yd^3 or 5.4 to 8.9 m^3).

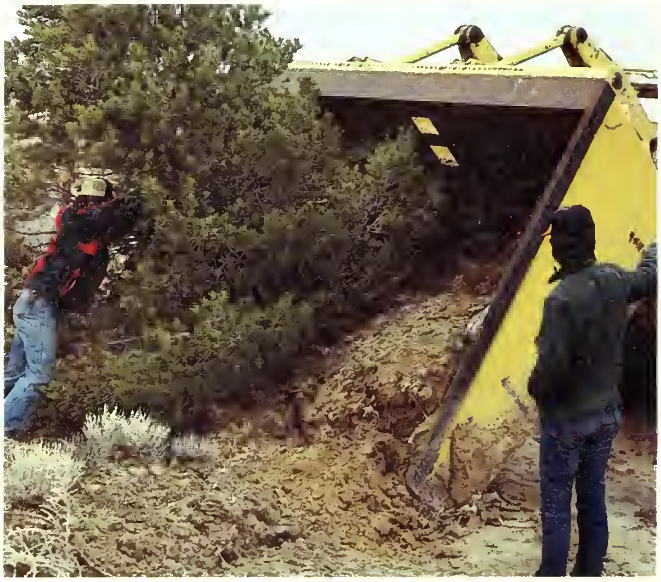


Figure 18.—Placing an 8-foot tall pinyon tree in a new location after lifting and moving with a large front-end loader. April 1980.

Mortality during the first summer following transplanting was 29 percent among junipers and 22 percent among pinyons. By the end of the third year following transplanting, 42 percent of the junipers had died compared to 24 percent of the pinyons.

Junipers 5 ft (1.5 m) or more in height suffered a 56 percent mortality, whereas mortality among pinyon trees 5 ft or more in height was 39 percent. Among juniper trees less than 5 ft in height, mortality was 32 percent. All pinyons less than 5 ft tall and junipers less than 3 ft (0.9 m) tall survived (fig. 19).

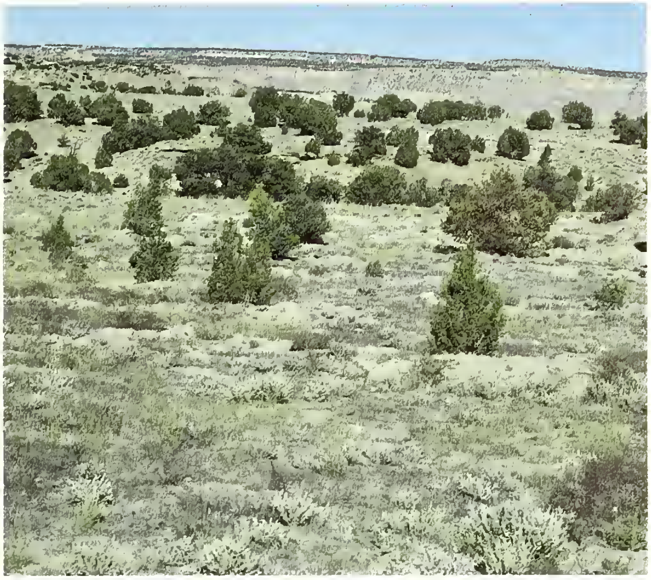


Figure 19.—All visible juniper and pinyon trees on the flat area in the foreground were transplanted with a large front-end loader. Five months later, several of the larger trees were dead.

Characterization of the Microclimate

The automatic data logging system installed at the 6-acre (2.4-ha) Persayo soil study area in May 1979 functioned almost flawlessly. Occasional summer electrical storms resulted in some brief periods when the date and time of day were recorded incorrectly. However, no data were lost, and a scan of sequential data passes enabled corrections of incorrectly recorded date and time. One soil temperature sensor became defective in the third week of November 1981 and was not replaced.

Appendix tables 42 through 45 show summaries of air and soil temperature data obtained over 40 months.

Energy, Minerals, Rehabilitation, Inventory and Analysis (EMRIA) Report No. 16 (Hodder and Jewell 1979) shows the mean annual temperature for the town of Emery as 45.8° F (7.7° C). The mean annual temperature for the 2 years for which we have complete data at the Emery study area was 49.3° F (9.6° C) in 1980 and 50.5° F (10.3° C) in 1981. This would indicate that the mean temperature is somewhat warmer at the study area, despite its 70-ft (20-m) higher elevation. The monthly mean temperatures at the town of Ferron are shown in appendix table 46. For the years 1980 through 1982, the mean annual temperature as measured at Ferron, the nearest currently maintained National Oceanic and Atmospheric Administration (NOAA) weather station, was less than 1.8° F (1° C) lower than the mean annual temperatures measured at the study area. The elevation at the Ferron weather station is 390 ft (119 m) lower than the study area.

Hodder and Jewell (1979), citing Richardson (1975), give the mean frost-free growing season as 132 days. However, as is the case with precipitation, the frost-free period varies greatly in the region of the Emery coal field. Freezing temperatures have been recorded in every month except July. From 1938 through 1981, the frost-free growing season averaged 126 days, with a range of 74 to 165. Mean dates of last spring frost and first autumn frost have been May 24 and September 28, respectively. In reality, however, a day in May or June that shows a minimum temperature of 32° F (0° C) does not "shorten" the growing season for most of our native plants. Once growth begins in the spring, freezing or subfreezing temperatures may cause some damage to young plant tissue, but growth continues unless the plant's entire aboveground part has been killed. The "growing season" for most native plants should be based on certain threshold temperatures of the air and soil. Different plant species will have different threshold temperatures. Appendix table 47 shows the length of frost-free period, and other miscellaneous microclimatic data for the Emery study area, for the years 1978 through 1982.

Appendix table 48 presents a comparison of the "growing degree days" (GDD) using a base temperature of 40° F (4.4° C) and an upper level of 78.8° F (26° C) for the years 1979 through 1982 at the study area.

For these calculations, the growing degree days for each day were determined using the equation:

$$\mathrm{GDD} = \frac{(\text{daily max. temp} \leq 78.8^\circ + \text{daily min. temp} \geq 40^\circ)}{2} - 40$$

That is, whenever the maximum temperature for a given day is higher than 78.8° F, then 78.8° F is used in the equation. Similarly, whenever the minimum temperature for a given day is lower than 40° F, then 40° F is used as the minimum temperature in the equation. (This method of calculating GDD was suggested to the authors by E. Arlo Richardson, Climatologist for the State of Utah.)

Appendix table 49 shows the long-term mean values for precipitation received at the town of Emery and precipitation amounts received at either the study area or the closest rain gage to the study area from January 1977 through September 1982. NOAA discontinued collection of data at Emery after April 1978. The U.S. Geological Survey maintained a recording rain gage for a short period during 1978 and 1979 about 0.25 mile (0.4 km) south of our Persayo soil study site.

On a calendar year basis, every year during the study received more precipitation than the long-term average reported for Emery. However, in arid regions plant growth is often more closely related to soil moisture accumulation during the previous cold portion of the year. For example, Hutchings and Stewart (1953) found a close correlation between herbage production on Utah's desert winter ranges and precipitation received between October 1 and September 30. Figure 20 shows the cumulative amount of precipitation received in the vicinity of Emery and, beginning in May 1979, at the Emery study area from 1978 through 1982. The first three

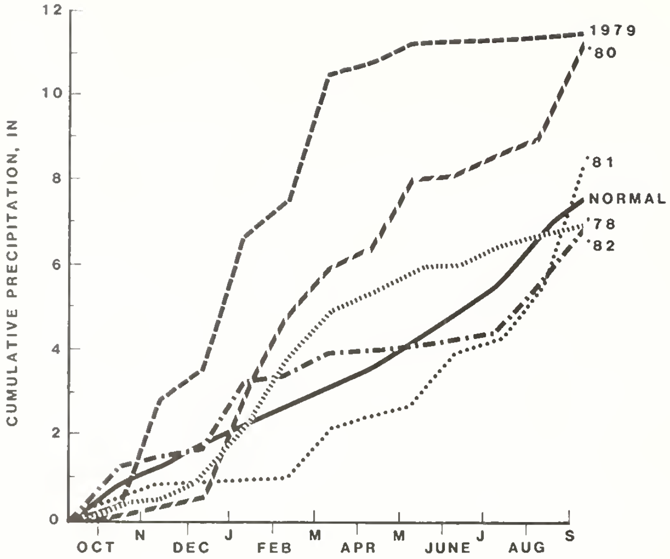


Figure 20.—Cumulative precipitation received at the Emery study area during each water year from 1978 to 1982, and for the normal water year.

growing seasons were wetter than normal, whereas the last two were drier than normal. The 1982 season did, however, receive enough overwinter precipitation (appendix table 50) to enable the cool season grasses, especially Russian wildrye, to produce moderately well.

The early growing season in the Emery area normally receives less precipitation than the last part of the growing season, July through September. Thus, plant species that respond to midsummer and late summer rainfall are favored. Plants such as galleta grass, blue grama grass, globemallow, and winterfat are quick to use summer rainfall. Even so, warm months in which only the average amount of rain falls are drought periods because of the high evapotranspiration rate in this region. Only the fortunate circumstance of one or more rainfall events of 0.4 inches (10 mm) or more in most growing seasons enables many plant species to survive and reproduce in this arid environment. In the 61 years of 1922 to 1982 an average of 3.3 such events occurred each year at Emery from May through September. The growing season of 1979 was one of only five during that period in which no rainfall events of that magnitude were recorded. So the growing season of 1979 was possibly favorable for plants that depend on winter moisture and enter a midsummer dormant period, but was an exceptionally unfavorable season for plants that depend on summer rainfall for survival or growth. Appendix figure 52 shows the probability of occurrence for a rainfall event of 0.4 inches for each month of the year.

Soil-water potential measurements, obtained from thermocouple psychrometers in 1980 and 1981, revealed some general trends. However, soil water potentials tend to vary considerably from spot to spot, creating difficulty in obtaining representative samples on large field plots.

As shown in appendix tables 51 and 52, soil moisture stress for plants (-15 bars or lower) usually became critical toward the end of June. Penoyer soil tended to reach lower water potentials earlier than Persayo soil. Castle Valley soil exhibited low water potentials at the 20-inch (51-cm) depth, possibly indicating a lack of soil water recharge at this particular site. Blue Gate shale soil material that had been severely disturbed by deep ripping usually exhibited lower water potential than nondisturbed soil. Interestingly, the shaley subsoil material rarely reached water potential levels below -10 bars.

Water potentials in gouged pits were often, but not always, higher than a nongouged location. This was especially noticeable following the heavy rains of early September 1981. Soil drying was much more severe in 1981 than in 1980. By mid-August 1981 some soils had become so dry that psychrometer readings could not be obtained.

CONCLUSIONS AND RECOMMENDATIONS

Based on data obtained over 5 years at the several sites discussed in this report, we reached the following conclusions and recommendations:

1. First-year seedling establishment of broadcast-seeded grasses and shrubs should be greater when the seeding is followed by light harrowing than when seeding is followed by cultipacking or when seeding is done with the gouger-seeder.
2. Yield of grasses and shrubs should be greater on Persayo and Penoyer soils when seeding is done with a gouger-seeder than when seeding is followed by harrowing or cultipacking. Sampling variation at Emery was too great to permit statistical confirmation of the numerical superiority of yields on gouged areas.
3. The establishment of a vigorous stand of grass on the principal study areas of Persayo and Penoyer soils on the Emery coal field was enhanced by the addition of an alfalfa hay soil amendment applied at a rate of 2.5 tons per acre (5.6 tons/ha). Although after 5 years grass yield and frequency of occurrence were not demonstrably greater on hay-amended areas than on nonamended areas, grasses remained visibly greener in color on amended soil, especially during portions of the growing season when soil moisture was at a high level.
4. On the smaller plots, where individual grass species were planted, the first-year density of grass seedlings was greater on hay-amended Persayo and Penoyer topsoils than on nonamended topsoil, but the observed difference could not be verified by statistical analyses. The addition of composted conifer tree bark to either Persayo or Penoyer soils inhibited grass seedling establishment on these same plots.
5. No consistent difference in either stand yield or average percent frequency of plants could be detected between topsoil and subsoil areas of the Persayo and Penoyer soils series.
6. Soil of the Penoyer series should support a more vigorous stand of perennial grasses than soil of the Persayo series. Of 10 species studied, only *Sitanion hystrix* exhibited better growth on Persayo soil than on Penoyer soil.
7. Indian ricegrass (*Oryzopsis hymenoides*) appears especially well adapted to soil of the Penoyer series and

should always be considered for use in revegetation programs on Penoyer soils.

8. Perennial grass and shrub establishment on topsoil of the Castle Valley soil series will be greatly superior to that on subsoil of the same series, and topsoil should be used for revegetation of reclaimed areas where the Castle Valley soil must be used.

9. Excellent results in establishing shrubs, especially chenopods, on soils of the Emery coal field can be obtained by using container-grown planting stock. Planting should be done no later than May 15, and plants should be given 1 to 2 qt (1 to 2 liters) of water at the time of planting. Additional supplemental water should only be necessary on clay soils.

10. Topsoil of the Castle Valley soil series should yield excellent shrub survival. However, growth rate of most shrubs should be better on Penoyer topsoil than on topsoils of the Castle Valley or Persayo series. Survival of well-adapted shrub species should be acceptably high on soils derived from Blue Gate shale or other shaley subsoil, but growth rate will be much slower than on topsoil materials.

11. Most species of chenopods, growing at a mean density of approximately 10 per 100 ft^2 ($0.9/m^2$), may reach nearly maximum height in the first 2 years after transplanting in the arid environment of the Emery coal field. However, diameter growth may continue to increase slowly in subsequent years.

12. Of the four soil materials on which alkali sacaton and four accessions of globemallow were established by interplanting among planted shrubs, Penoyer topsoil was superior in terms of survival and growth.

13. The following shrub species are recommended for use in reclamation of surface-mined lands of the Emery coal field:

A. On all soil materials studied—
   Fourwing saltbush
   Bonneville saltbush
   Broadscale saltbush
   Trident saltbush
   Prostrate summercypress
   Mediterranean camphorfume
   Winterfat
   Plumed whitesage
B. Species adapted mostly to sandy soils—
   Black sagebrush
   Nevada ephedra
   Fourwing saltbush X Cuneate saltbush hybrid
C. Species unsuited to sandy soils—
   Corymbed eriogonum
D. Species showing promise; further study desirable—
   Fourwing saltbush X Trident saltbush hybrid
   Fourwing saltbush X Idaho saltbush hybrid
   Bonneville saltbush X Trident saltbush hybrid

14. Utah juniper trees 3 ft (0.9 m) or less in height can be successfully lifted and transplanted with a front-end loader of the size and type used in our trial at Emery. Pinyon trees 5 ft (1.5 m) or less in height can be successfully transplanted in the same manner. Transplanting should be done in early spring to allow as long a time as possible for root regrowth to occur before soil moisture is diminished.

PART II: RESEARCH ON THE ALTON COAL FIELD

STUDY AREAS

The Alton coal field lies in Kane County, southwestern Utah, adjacent to the southern edge of the Paunsagunt Plateau. It is in the extreme northern corner of the Grand Canyon Section of the Colorado Plateau Province (Thornbury 1965). The study sites are approximately 20 miles (32 km) north-northeast of the town of Kanab and about 10 miles (16 km) southeast of the town of Alton (appendix figure 62).

Vegetation on the Alton coal field is dominated by the pinyon-juniper woodland type. Mountain brush and sagebrush communities are interspersed within the pinyon-juniper. The mountain brush areas are dominated by gambel oak (*Quercus gambelii* Nutt.), big sagebrush (*Artemisia tridentata* Nutt. var. *tridentata*), low sagebrush (*Artemisia arbuscula* Nutt.), and mountain snowberry (*Symphoricarpos oreophilus* Gray). The sagebrush type is characterized principally by big sagebrush, low sagebrush, rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.), and antelope bitterbrush (*Purshia tridentata* [Pursh] DC). Although grasses and forbs are less important components of the vegetation of much of the Alton coal field, native species of grasses such as Indian ricegrass, blue grama, western wheatgrass (*Agropyron smithii* Rydb.), and squirreltail (*Sitanion hystrix* [Nutt.] J. G. Sm.) may be found, along with such introduced species as cheatgrass (*Bromus tectorum* L.), tall wheatgrass (*Agropyron elongatum* [Host] Beauv.), and crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.). Conspicuous forbs are globemallow (*Sphaeralcea* spp.), penstemon (*Penstemon* spp.), spiderflower (*Cleome* spp.), and coyote tobacco (*Nicotiana attenuata* Torr. ex Wats.). In terms of total number of plant species present, the flora of the Alton coal field is quite rich, though many species are only occasionally found.

Soil orders identified by the U.S. Department of Agriculture, Soil Conservation Service, on the Alton coal field are Entisols, Mollisols, Aflisols, and Inceptisols (USDI 1975). The coal-bearing strata are all within the Dakota sandstone formation of Cretaceous age. Soils are variable in texture, ranging from silty clays derived from the Tropic Shale Formation, which overlies the Dakota, to sandy loams derived from the Dakota sandstone. Most surface soils exhibit near neutral to slightly alkaline soil reactions, and salinity and sodicity present no problems for plant growth. However, certain strata of subsoil material have sodium adsorption ratios and conductivity values inimical to plant growth.

The climate of the Alton study area is probably somewhat milder and slightly drier than at the town of Alton, the nearest permanent weather station. Average annual precipitation there has been 16.4 inches (417 mm). The study area is roughly 500 ft (152 m) lower in elevation than the town, and from examination of the scanty data obtained (USDI 1979) closer to the study area, the average annual precipitation there is apparently between 14 and 15 inches (356 and 381 mm). At the Alton study site, the average precipitation ranges between 1.19 and 1.49 inches (30 and 37 mm) for 7 months of the year (appendix table 65). Of the remaining 5 months, May and June are the driest, averaging about 0.7 inches (18 mm). August, December, and January receive about 1.8 inches (46 mm) per month. The long-term average for the frost-free season at Alton is 108 days.

METHODS

The Alton coal field has considerably more danger of severe soil erosion than does the Emery coal field. The average annual precipitation at Alton is more than twice that at Emery, and high intensity midsummer rain storms are more common. Because of the erosion hazard and the steeper terrain at Alton, two studies were initiated in autumn 1976 to evaluate the effects of different surface treatments and organic soil amendments on the establishment and growth of vegetation following direct seeding.

Site Preparation and Soil Amendments

We selected an 8-acre (3.24-ha) site occupied by an old-growth pinyon-juniper stand with a predominantly southeastern exposure and slopes of 5 to 20 percent. The site is in sec. 18, T40S, R4½W in Kane County, Utah, at an elevation of approximately 6,550 ft (1 996 m). All trees were bulldozed from the study area, piled, and burned (fig. 21). Using a D-8 Caterpillar tractor, an 8- to 15-inch (20- to 38- cm) layer of topsoil was removed from most of the area and stockpiled in two windrows (fig. 22).

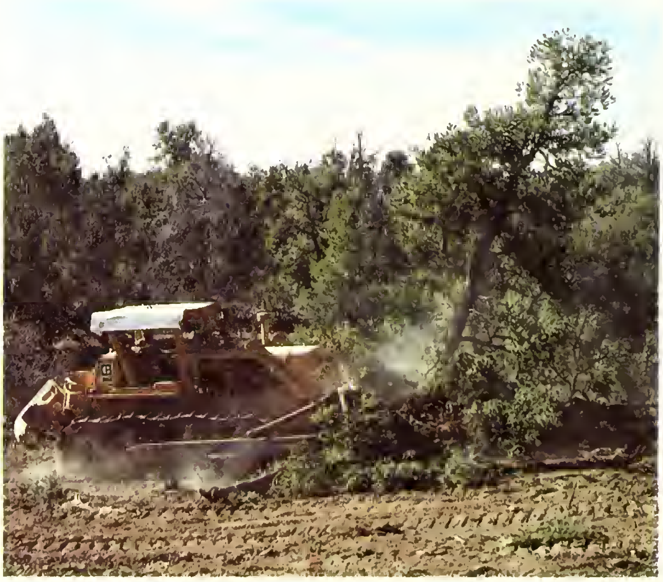


Figure 21.—Removing a dense stand of juniper and pinyon trees prior to the initiation of research on the Alton 8-acre study area. November 1976.

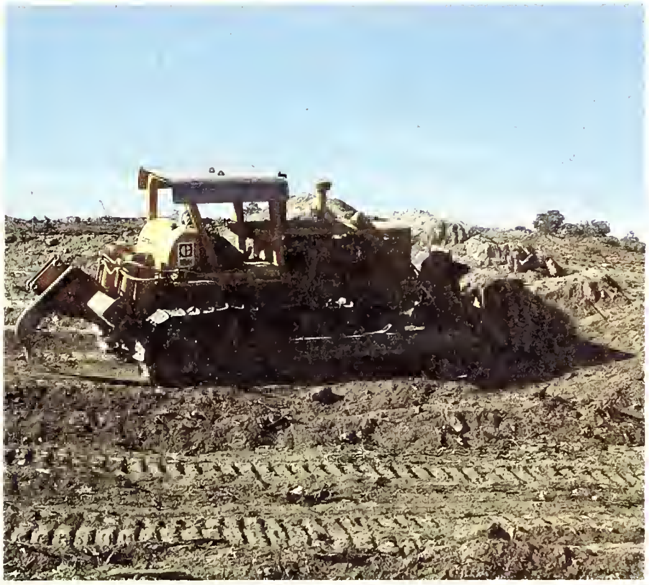


Figure 22.—Stockpiling topsoil in windrows prior to deep ripping on the Alton 8-acre study area. November 1976.

The subsoil on portions of the area was then "ripped" to a depth of 30 inches (76 cm) and smoothed by blading, followed by the replacement and smoothing of the topsoil material. With the addition of a grass hay soil amendment to part of the area (fig. 23), field crews applied the following treatments (see appendix fig. 53 for field design):

1. Topsoil removed, subsoil ripped, topsoil replaced, area gouged and seeded
2. Same as 1 except that contour furrowing followed topsoil replacement rather than gouging
3. Same as 1 except that grass hay was rotovated into the top 8 inches (20 cm) of soil at a rate of 2.5 tons per acre (5.6 tons/ha) and the area was not gouged prior to seeding
4. Topsoil was left in place, the area gouged and seeded
5. The original topsoil covered with stockpiled topsoil that was later removed, and the surface gouged prior to seeding

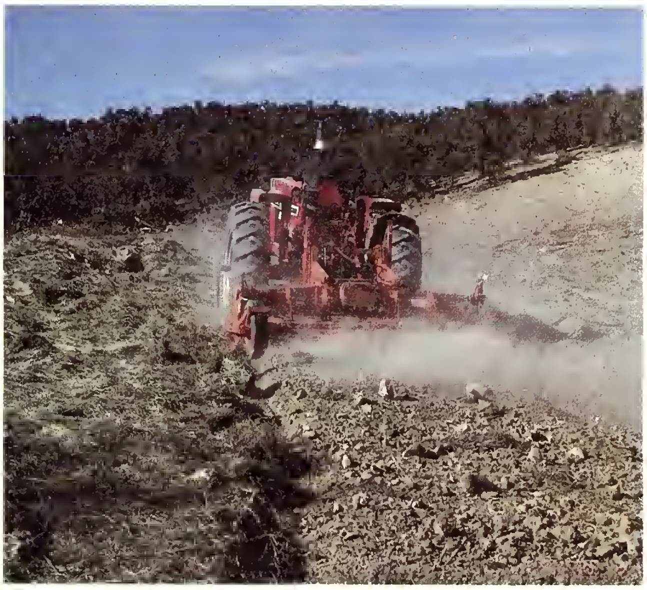


Figure 23.—Rotovating grass hay into the top 8 inches of topsoil after the topsoil had been replaced over ripped subsoil on the Alton 8-acre study area. November 1976.

Seeding was done immediately after site preparation in late December, using hand-operated Cyclone seeders. The seed mixture used is shown in table 19. At the time of seeding the soil surface was quite rough, loose, and dry. No effort was made to cover the seed or firm the seedbed.

In September 1977, we sampled all treatments to obtain data on density, frequency, and plant height, but we made no effort to distinguish individual species of grasses or forbs. Similar data were obtained in September 1978, when it was practical to record the data by individual species. In August 1979 and July 1980, 1981, and 1982, data were obtained on all grasses, all forbs, and all shrubs (without distinguishing species), and on mean plant height and estimated yield of grasses, legumes, and shrubs.

Table 19.—Composition of seed mixture sown on the 8-acre study area, Alton coal field

Common name	Scientific name	Source	Pounds per acre
'Nordan' crested wheatgrass	*Agropyron desertorm*	South Dakota	4
Intermediate wheatgrass	*Agropyron intermedium*	South Dakota	4
'Luna' pubescent wheatgrass	*Agropyron tricophorum*	?	4
Russian wildrye	*Elymus junceus*	Montana	4
'Nomad' alfalfa	*Medicago sativa*	?	1
Yellowblossom sweetclover	*Melilotus officinalis*	Canada	1
Antelope bitterbrush	*Purshia tridentata*	Nevada	2
Fourwing saltbush	*Atriplex canescens*	Kane Co., UT	2
Winterfat	*Ceratoides lanata*	Sanpete Co., UT	0.5
Green ephedra	*Ephedra viridis*	Sanpete Co., UT	1
Cliffrose	*Cowania stansburiana*	Salt Lake Co., UT	1

Organic Amendments and Grass Species

To further determine the effects of hay and composted bark amendments on the establishment and growth of selected grass species, and to compare the response of those species when the amendment was added to both topsoil and subsoil, an additional study was made. In December 1976, two portions of the 8-acre (3.2-ha) area described above were set aside. As on the larger portion of the area, the topsoil was removed and stockpiled, and the subsoil ripped and smoothed. The following treatments were then applied, with two replications on one portion and a third on the other portion:

1. Eight inches (20 cm) of topsoil replaced over the subsoil
2. Same as 1, plus grass hay rotovated into the topsoil at a rate of 2.5 tons per acre (5.6 tons/ha)
3. Same as 1, plus composted conifer bark rotovated into the topsoil after being spread to a depth of 1 inch (2.5 cm)
4. Subsoil rotovated to a depth of 8 inches
5. Same as 4, with grass hay rotovated into the top 8 inches of subsoil at a rate of 2.5 tons per acre
6. Same as 4, with composted bark rotovated into the top 8 inches of subsoil at the same rate as in 3

Each of the six treatments were applied to an area 15 ft wide by 100 ft long (4.6 m by 30.5 m) in each of the three replications. In turn, each such strip was divided into 10 subplots, 10 ft by 15 ft (3 m by 4.6 m), and a different species of grass sown on each subplot. The field design is shown in appendix figure 54. Seeds were broadcast by hand on the loose soil at a rate of 20 lb per acre (22.7 kg/ha). Species used and source of each, where known, are shown in table 20.

In September 1977 and 1978, we obtained data on density, frequency, and plant height. In August 1979 and July 1980, 1981, and 1982, we obtained data on frequency, plant height, and yield (weight-estimate method).

Table 20.—Grass species used on soil type–soil amendment plots at the 8–acre study area, Alton coal field

Common name	Scientific name	Source
'Fairway' crested wheatgrass	*Agropyron cristatum*	?
'Alkar' tall wheatgrass	*Agropyron elongatum*	?
'Whitmar' bluebunch wheatgrass	*Agropyron inerme*	Aberdeen, ID
Intermediate wheatgrass	*Agropyron intermedium*	?
'Sodar' streambank wheatgrass	*Agropyron riparium*	Canada
'Rosana' western wheatgrass	*Agropyron smithii*	Montana
'Luna' pubescent wheatgrass	*Agropyron tricophorum*	?
Smooth bromegrass	*Bromus inermis*	?
Basin wildrye	*Elymus cinereus*	Aberdeen, ID
Russian wildrye	*Elymus junceus*	Montana

Grass and Shrub Species

To determine the value of different species of grasses and shrubs for use in the revegetation of some of the different soil materials found on the study area, we conducted research on a 3-acre (1.2-ha) site and supplemented with a greenhouse bioassay study. The study site is less than 0.25 mile (0.4 km) east-southeast of the 8-acre (3.2-ha) site referred to above. Situated on a west-facing slope of approximately 25 percent, the site originally included a 15-ft (4.6-m) deep trench along the contour, of about 0.2 acre (0.08 ha), that exposed the top 3 to 5 ft (0.9 to 1.5 m) of a coal seam. To prepare the site for the planned research, the trench was filled and graded to the original slope of the land, using primarily the material originally taken from the trench. Then all trees were bulldozed from an area of 3 acres, with the originally trenched area in the center of the 3-acre tract. Next, starting near the top of the slope, field crews applied four soil materials as follows:

1. A 50-ft (15.2-m) strip of sandy loam topsoil was left in place, but ripped to a depth of 2 ft (0.6 m) and not releveled
2. A 50-ft wide area was stripped of approximately 1 ft (0.3 m) of topsoil and 2 ft of gravelly clay loam subsoil, leaving the silty clay subsoil exposed; this area was also ripped and the furrows thus created left in place
3. Two 25-ft (7.6-m) wide terraces were formed by removing the gravelly clay loam and silty loam subsoils down to a layer of dark-colored carbonaceous shale that lay immediately above the coal seam; depth of the carbonaceous shale layer was about 3 ft (0.9 m)
4. A 50-ft wide strip of "fill" material composed of the gravelly clay loam subsoil was taken from the area described in 2 above, and transported downhill to an area just below the terraces

On each of the four areas of different soil material, the same 12 species of grasses were seeded (broadcast by hand) on a 10- by 50-ft (3- by 15.2-m) plot, with two replications. The field design is shown in appendix figure 55. All species were seeded at a rate of 20 lb/acre 22.7 kg/ha) except for a rhizomatous type of crested wheatgrass and a hybrid of *Agropyron spicatum* and *Agropyron repens*, which were sown at a rate of 10 lb/acre (11.4 kg/ha).

Data were taken in the same manner and at the same time of year as described for the studies on the 8-acre (3.2-ha) area. Table 21 shows the grass species used and the source of seed, where known.

We did a greenhouse bioassay study using four soil materials from the 3-acre (1.2-ha) site (sandy loam topsoil, gravelly clay loam subsoil, carbonaceous shale, and a silty clay subsoil) to compare the soils as growing media for plants. A factorial experimental design was used, with four soils, four amendments, with two replications.

The soil materials were placed in plastic trays and treated as follows: (1) a 1-inch (2.5-cm) layer of composted conifer bark spread over the surface and then mixed thoroughly with the soil, (2) a 0.5-inch (1.3-cm) layer of composted bark incorporated with the soil in the same way, (3) ammonium nitrate thoroughly mixed into the soil at a rate of 100 lb N per acre (17.9 kg/ha), and (4) no amendment, to serve as a control treatment.

Bromus inermis and *Agropyron elongatum* were used as test species. Fifty seeds of each species were sown in each tray of soil material (two rows of 25 seeds of each species). We obtained data on seedling emergence and

Table 21.—Grass species sown on four different types of soil materials at the 3–acre site, Alton coal field

Common name	Scientific name	Source
'Fairway' crested wheatgrass	*Agropyron cristatum*	?
Crested wheatgrass (rhizomatous)	*Agropyron cristatum*	ARS; Logan, UT
'Alkar' tall wheatgrass	*Agropyron elongatum*	?
'Whitmar' bluebunch wheatgrass	*Agropyron inerme*	Aberdeen, ID
Intermediate wheatgrass	*Agropyron intermedium*	?
'Sodar' streambank wheatgrass	*Agropyron riparium*	Canada
'Rosana' western wheatgrass	*Agropyron smithii*	Montana
Hybrid wheatgrass	*A. spicatum* x *A. repens*	ARS; Logan, UT
'Luna' pubescent wheatgrass	*Agropyron trichophorum*	?
Smooth bromegrass	*Bromus inermis*	?
Basin wildrye	*Elymus cinereus*	Aberdeen, ID
Russian wildrye	*Elymus junceus*	Montana

plant height over a 60-day growing period. At the end of the period all plants were clipped, air-dried, and weighed.

To compare the survival and rate of growth of selected shrub species in competition with the 12 species of grass evaluated on the 3-acre site, container-grown shrubs were planted into the year-old grass plots in May 1978. Ten species of shrubs were planted in only one replication of the grass plots. A single row of each species was planted across the grass species plots on each of the four types of soil material. Shrubs were planted on a 5-ft (1.5-m) grid so that two plants of each shrub species were in each grass species plot on each soil type. Appendix table 53 lists the species of shrubs planted and their source, when known. Appendix figure 55 shows the field design. In every autumn from 1978 through 1982, we obtained data on survival and size (height and diameter) of all shrubs.

Plant Species on Soil and Overburden Types

In autumn 1976 we started a study in cooperation with Utah International, Inc., to test the possibility of establishing vegetation on a carbonaceous shale overburden material without applying a topsoil covering. Additional objectives of the study were (1) to compare the establishment and longevity of vegetation on the carbonaceous shale with that on carbonaceous shale covered with different kinds of topsoil available in the area, (2) to monitor soil moisture status throughout the growing season, and (3) to monitor the status of soil salinity.

A 0.5-acre (0.2-ha) study area in sec. 14, T40S, R5W, in Kane County, Utah, was cleared of all native vegetation and fenced to exclude rodents, livestock, and deer. On the nearly level site, two areas, each 30 ft by 83 ft (9.1 m by 25.3 m) were excavated to a depth of 40 inches (102 cm) and filled with 30 inches (76 cm) of carbonaceous shale from above the nearby coal seam. Using plywood partitions, each of the two areas was then subdivided into eight 10-ft by 30-ft (3-m by 9-m) plots. Four adjacent plots constituted one replication of the four following treatments: (1) unweathered carbonaceous shale, 40 inches (102 cm) deep; (2) 30 inches (76 cm) of the same shale, covered with 10 inches (25.4 cm) of loam topsoil; (3) 30 inches of the same shale, covered with 10 inches of sandy loam topsoil; and (4) 30 inches of the same shale covered with 10 inches of silty clay topsoil (appendix fig. 56).

After being leveled, the lower half of each of the 16 plots was fertilized with ammonium sulfate and treble super phosphate at the rate of 80 lb each of elemental N and P per acre (90 kg/ha). In November a seed mixture comprised of six species of grasses, six species of forbs, and six species of shrubs was sown by hand broadcasting and raking. Grasses and forbs were each sown at a rate of 1 lb of pure live seed per acre (1.12 kg/ha), while each shrub species was sown at a rate of 2 lb/acre (2.24 kg/ha) (except for *Ceratoides lanata*, which was sown at a 1 lb rate).

Colman fiberglass soil moisture sensors were installed at three depths—8, 18, and 30 inches (20, 46, and 76 cm)—at a single location on each plot. The sensors included a thermistor, which enabled us to also measure soil temperature. In 1977, 1978, 1979, and 1981, plant density and cover were recorded from a sample of 24 subplots, each 1 ft^2 (0.09 m^2), on each of the 16 study plots. Vegetative production was sampled in August 1979, 1980, and 1981 by clipping and weighing all grasses and forbs from one-fifth of the area of each of the 16 plots. Productivity of shrubs was estimated by the weight-estimate method (Pechanec and Pickford 1937).

Soil moisture and temperature were measured on five occasions during the growing season of 1977, and at approximately weekly intervals during the growing seasons of 1978 through 1980. Soil samples were taken in the autumns of 1978 through 1982 to determine soil salinity status.

We subjected data to analyses of variance and tests of mean separation to evaluate differences in vegetation on the four soil materials. The plant species used in the seed mixture are shown in appendix table 54.

Shrub and Forb Species

We made three plantings on the Alton study area, one in 1977 and two in 1980, to evaluate survival and growth rates of a wide variety of shrub species and several forb species. The results will aid those responsible for selecting suitable plant species for use in surface mine reclamation on the Alton coal field.

The 1977 planting was made on a disturbed core drilling site adjacent to the 8-acre (3.2-ha) study site previously described. The site was enlarged to approximately 75 by 144 ft (23 by 44 m) by the removal of several trees. Container-grown plants of 27 shrub species and three forb species were planted in individual plots of 6 ft by 15 ft (1.8 by 4.6 m). Ten plants of a given species were planted in each plot, in two rows of five plants each, spaced 3 ft (0.9 m) apart in both directions. Each species plot was represented once in each of four blocks. Planting was done in mid-June, and each plant was given 0.5 gal (1.9 liters) of water at the time of planting. No other supplemental water was provided. We obtained data on survival and plant growth in autumn of 1977, spring and autumn 1978, and the autumns of 1979 through 1982. Appendix table 55 shows the species planted and original seed source, if known. Appendix figure 57 shows the field plot design.

On May 28, 1980, field crews planted 18 accessions of shrubs, seven herbaceous accessions, and four accessions of trees on a reconstructed soil material about 200 yards (183 m) west of the 8-acre (3.2-ha) study site. Utah International, Inc., had excavated a 50-ft (15-m) deep pit to obtain samples of the coal vein at that location, then refilled the excavation and graded the site.

All plants used had been grown in the greenhouse in plastic, Spencer-Lemaire type containers except for hybrid poplar (*Populus* spp.), which had been propagated from hardwood cuttings in 0.5-gal (1.9-liter) pots, and gambel oak (*Quercus gambelii*), which had been grown in Japanese paper pots. Planting was done in holes made with a gasoline-powered soil auger. No supplemental water was applied at the time of planting, nor at any time thereafter.

Field crews planted 15 accessions of shrubs and all of the herb accessions in a randomized block design, with four blocks. Five plants of each accession were planted in a single row in each block. Spacing was on a 4-ft (1.2-m) grid. The remaining three accessions of shrubs and the four accessions of trees were planted in the form of a windbreak. Two rows of 10 plants of each accession were planted, with 8 ft (2.4 m) between rows and a 10-ft (3-m) spacing between plants within each row.

We recorded data on plant survival and size each autumn from 1980 through 1982. Appendix table 56 lists the species used and original seed source, if known. Appendix figures 58 and 59 show the field plot design.

Also, in May 1980, field crews planted 20 accessions of fourwing saltbush east of, and adjacent to, the randomized block shrub planting. The saltbush planting was also a randomized block design, with three blocks. Each accession was planted in a separate row, five plants per row, with 20 rows per block. Plant spacing was on a 4-ft (1.2-m) grid. Appendix table 57 lists the sources of the accessions used. Appendix figure 60 shows the field plot design. We obtained data on plant survival and plant size each autumn from 1980 through 1982.

Characterization of the Microclimate

In May 1979, two battery-powered (solar-charged) automatic data loggers were installed, one at the 8-acre (3.2-ha) site and one at the Utah International site 1.9 miles (3 km) to the west. The elevation of the latter site—6,440 ft (1 963 m)—is 110 ft (34 m) lower than the 8-acre site. Ambient air temperature 54 inches (137 cm) and 12 inches (30 cm) above ground, soil temperature 2 and 8 inches (5 and 20 cm) below the surface, and cumulative precipitation received by an unheated tipping bucket rain gage were monitored at hourly intervals. In addition, thermocouple psychrometers were placed in the soil at depths of 8 and 20 inches (20 and 51 cm) at (1) three locations on each of the six treatments of one replication of the soil amendment study on the 8-acre site, and (2) three locations on each of the four soil materials on the 3-acre (1.2-ha) site. Psychrometers were read at weekly intervals from late June through October 1979. However, problems with faulty voltmeter functioning made many readings in 1979 suspect. Readings were taken at weekly intervals from July 12 through September 28, 1980, and from May 12 through September 26, 1981.

RESULTS AND DISCUSSION

Establishment of grasses and legumes by broadcast seeding on loose soil materials was successful even though no effort was made to cover the seed. However, silty clays were definitely the poorest soil materials in terms of stand establishment. The advantages of returning a good quality topsoil to the surface of the area to be revegetated was clearly demonstrated. We also found that a side variety of plant species can be used in the environment of the Alton coal field.

Site Preparation and Soil Amendments

The severe drought during autumn 1976 and the first third of 1977 prevented normal early spring germination and seedling emergence of the species seeded in December 1976. However, fair to good seedling emergence occurred on all treatments following a rainy period in the latter half of May (2.34 inches or 59 mm at the town of Alton).

At the end of the first growing season, frequency of grass plants averaged 92 percent on the ripped area where hay had been rotovated into the soil surface, compared to an average frequency of 52 percent on ripped areas receiving no hay amendment (table 22). Mean percent frequency of legumes and shrubs on the hay-amended area was 40 and 4 percent, respectively, compared to an average of 21 and 2.5 percent for legumes and shrubs on nonamended areas. Mean maximum number of grass seedlings per square foot was 12.8 ($138/m^2$) on the hay-amended area compared to 5.2 ($56/m^2$) on nonamended areas. Areas severely disturbed by topsoil removal, ripping, and topsoil replacement exhibited a mean frequency of 66 percent for grasses, compared to a mean frequency of 42 percent on areas where topsoil was left in place.

Above-average precipitation during the winter of 1977 to 1978 resulted in excellent plant growth in 1978. Smooth brome was a prominent component of the grass stand where the hay amendment had been used because it was a major component of the hay.

The total percent frequency of grasses tended to remain somewhat higher on the hay-amended area than on nonamended areas throughout the study because of the well established, rhizomatous smooth brome. With smooth brome included, the mean frequency of grasses on the hay-amended area was 97 percent in 1982. During this period, the vegetative stand density

Table 22.—Frequency (percent) and yield (lb/acre, air–dry) of plants according to treatment and year, Alton coal field

		Grasses		Legumes		Shrubs		Total
Treatment	**Year**	**Freq.**	**Yield**	**Freq.**	**Yield**	**Freq.**	**Yield**	**yield**
0 = Strips where topsoil was stockpiled. Surface gouged after redistribution of topsoil	1977	43	—	21	—	2	—	—
	1978	57	—	14	—	4	—	—
	1979	60	[1]1,400	16	490	2	—	[2]1,890
	1980	63	2,168	12	662	1	0	2,830
	1981	53	475	14	347	2	14	836
	1982	78	910	16	420	3	34	1,364
1 = Topsoil removed, subsoil ripped, topsoil replaced, surface gouged	1977	52	—	21	—	3	—	—
	1978	67	—	19	—	4	—	—
	1979	71	1,325	16	430	3	—	1,755
	1980	75	1,294	15	439	1	10	1,743
	1981	78	508	13	271	3	23	802
	1982	88	810	10	380	2	53	1,243
2 = Topsoil left in place, surface gouged	1977	40	—	17	—	1	—	—
	1978	61	—	13	—	5	—	—
	1979	70	895	10	105	4	—	1,000
	1980	73	1,079	4	160	3	23	1,262
	1981	73	580	6	127	2	12	719
	1982	82	590	6	390	6	93	1,073
3 = Topsoil removed, subsoil ripped, topsoil replaced, surface contour furrowed	1977	53	—	22	—	8	—	—
	1978	53	—	22	—	8	—	—
	1979	58	1,675	16	765	3	—	2,440
	1980	53	1,175	17	627	2	94	1,896
	1981	62	583	22	498	2	4	1,085
	1982	77	720	17	620	4	150	1,490
4 = Topsoil removed, subsoil ripped, topsoil replaced, hay amendment added	1977	92	—	40	—	4	—	—
	1978	[3]76	—	19	—	5	—	—
	1979	87	1,950	14	170	1	—	2,120
	1980	89	1,637	21	517	1	2	2,156
	1981	78	537	11	118	1	4	659
	1982	79	830	17	180	0	0	1,010

[1] Dry weight on all treatments in 1979 was estimated to be 50 percent of green weight.

[2] Smooth brome constituted 31, 35, 36, and 45 percent of the total yield in 1979, 1980, 1981, and 1982, respectively.

[3] Percent frequency shown for treatment 4 is exclusive of the smooth brome component, except in 1977.

appeared to reach essentially similar status on the rest of the study area.

The legume component of the established vegetation contained many vigorous yellow sweetclover plants in the second growing season. However, few remained by 1979, and sweetclover was rarely encountered in subsequent years. Alfalfa became the primary seeded legume, and despite an apparent steady decrease in percent frequency during the 6 years, many vigorous plants remain in the stand (fig. 24).

The most prominent shrub species in the first growing season were fourwing saltbush, winterfat, and bitterbrush, in that order. Cliffrose and green ephedra seedlings were only occasionally encountered. During the subsequent 5 years, overall percent frequency of shrubs remained relatively constant (table 22). Winterfat decreased drastically in numbers. But bitterbrush and cliffrose became much more conspicuous and productive. After 6 years, many excellent fourwing saltbush shrubs remained (fig. 25), but green ephedra was extremely rare.

Table 22 also shows mean estimated yields of grasses, legumes, and shrubs, beginning with the third growing season for grasses and legumes and the fourth season for shrubs. The severely disturbed area, where a hay amendment was added to the soil, yielded slightly more

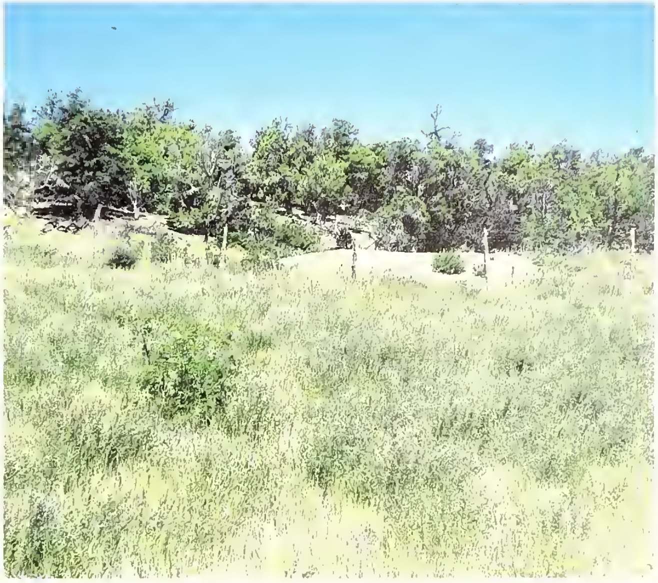


Figure 24.—Vigorous plants of 'Nomad' alfalfa intermixed with a good stand of perennial grasses in the sixth year following seeding on the Alton 8-acre study area. July 15, 1982.

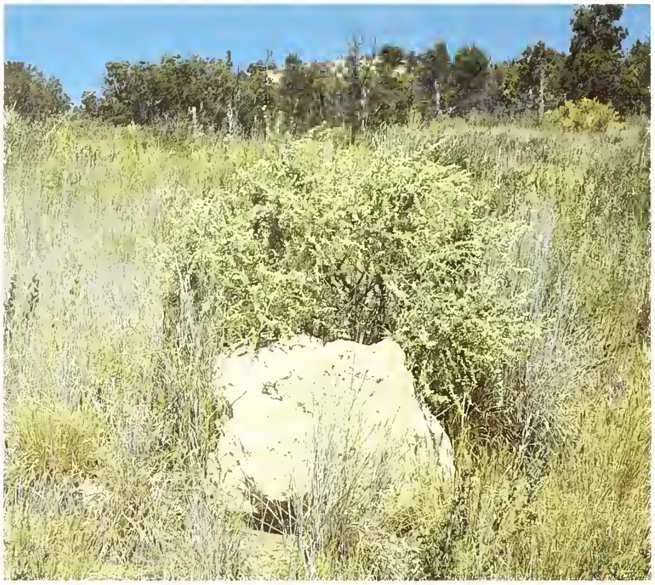


Figure 25.—Excellent Atriplex canescens *shrub established by seeding in autumn 1976 on the Alton 8-acre study area. July 1982.*

vegetative growth in 1979 than similarly disturbed areas that were not amended. In subsequent years the other treated areas yielded equally as well as the hay-amended area. In fact, the establishment of smooth brome on the hay-amended area may have resulted in lower overall yield, as this species has not been especially vigorous on the study area despite occupying considerable space and competing successfully with the four seeded grasses.

The two narrow strips across the study area on which topsoil had been stockpiled sustained a more vigorous growth of grasses throughout the study period than did most of the other treated areas, even though the percent frequency of grasses was low. Coupled with high yields by alfalfa, the excellent yield of vigorous grass plants resulted in much higher total yield than occurred on the other areas where topsoil was left in place. A possible explanation of this is that not as much topsoil was removed during redistribution to the rest of the area as was added to the strips during stockpiling. The increased depth of topsoil may thus have created improved growing conditions.

Yield of the mixed grass and alfalfa stand seemed to "peak" in the third and fourth growing season (fig. 26). Rumbaugh and others (1982) found that in mixed plantings of crested wheatgrass, fourwing saltbush, and alfalfa, the crested wheatgrass was stimulated to yield more than when it grew alone; total vegetative production from the mixture was greater than from pure stands of crested wheatgrass. In our study, after 6 years yield appeared somewhat greater on those portions of the 8-acre (3.2-ha) area where a good mixed stand of alfalfa and grass occurred (fig. 27).

Legume yields fluctuated from year to year, with 1981 being particularly good for alfalfa growth. After 6 years, alfalfa still contributed a significant portion of overall forage yield.

Shrub yields, first sampled in 1980, gradually increased on all treatments except the hay-amended area, where few shrubs were able to survive in competition with the dense grass stand established in the first growing season. Bitterbrush and cliffrose were growing vigorously on the study area in 1982 (fig. 28), especially where grass competition was not severe. Numerous vigorous fourwing saltbush plants were still present. These shrub species should continue to increase in yield for several more years.

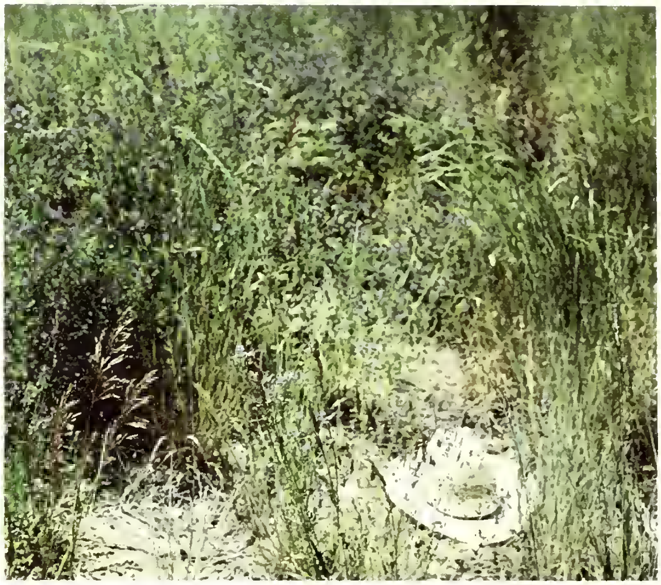


Figure 26.—A broadcast-seeded mixture of perennial grasses and alfalfa, in the year of peak production (fourth growing season) on the Alton 8-acre study area. July 17, 1980.

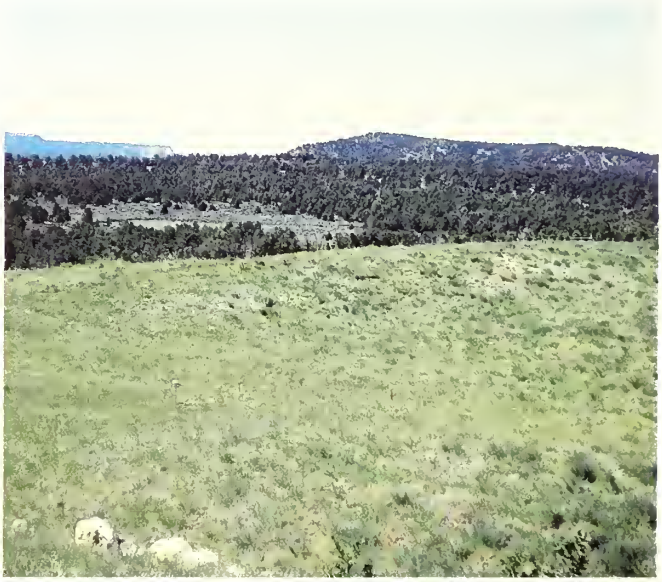


Figure 27.—View of the Alton 8-acre study area in the sixth growing season. A portion of the area where a grass hay soil amendment was used is visible in the left-center. Dense growth of Bromus inermis *in this portion of the area severely limited establishment of alfalfa, numerous plants of which are visible on the remaining area. July 15, 1982.*

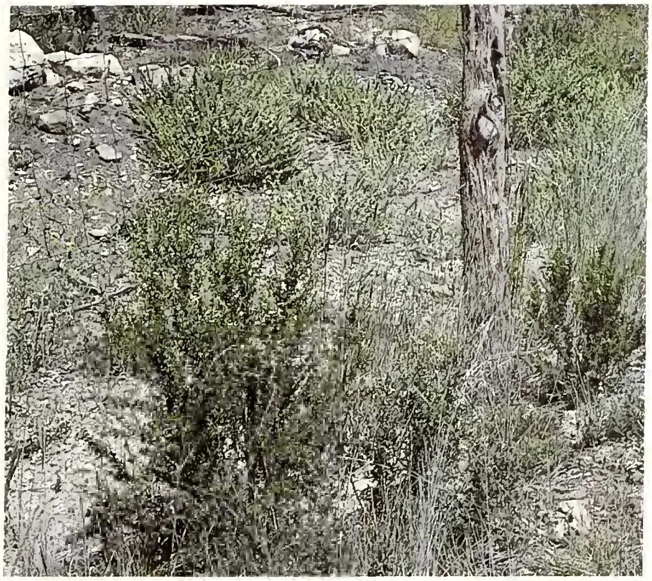


Figure 28.—Good Cowania stansburiana *plants, in the sixth growing season on the Alton 8-acre study area. Cliffrose, antelope bitterbrush, and fourwing saltbush successfully competed with perennial grasses and alfalfa, although limited mostly to spots where herbaceous plants were least dense. July 15, 1982.*

Of the four grass species sown in 1976, all proved well adapted to the environmental conditions of the study area. No data were taken on species composition, but after 6 years "Nordan" crested wheatgrass remained the most common species. Intermediate wheatgrass and pubescent wheatgrass made up a significant portion of the grass stand, while Russian wildrye constituted a much smaller proportion of the stand.

In the reclamation of surface mined lands, the absolute volume of vegetation produced each year should not be a land manager's highest concern. Of greater concern is that sufficient established vegetation be maintained to preserve the soil. Total amount of vegetative growth will vary with annual growing conditions. Dense stands of grass are seldom found on the Alton coal field. Instead, the pinyon-juniper forest predominates, with interspersed areas dominated by shrubs. Establishment of a good stand of several adapted grass species, as soon as the land is restored to the desired relief, is the best way to stabilize the reconstructed soil material. The addition of forbs (especially legumes) and shrubs to the vegetative composition is desirable for a number of reasons that won't be dwelt upon here.

Although the initially established vegetation on a reclaimed area may decrease in terms of herbage yield and ground cover, the large amount of organic matter added to the soil will greatly improve the soil's fertility and physical properties. Ultimately, the land manager and researcher desire to learn the potential of the reclaimed area for supporting a particular type and quantity of vegetation. Only long-term study can give the answers.

On the 8-acre (3.2-ha), 3-acre (1.2-ha), and Utah International cooperative study sites, total plant yield diminished in the fifth and sixth year of study, yet on most areas soil cover remained entirely adequate to protect the soil from erosion.

Organic Amendments and Grass Species

As on the larger portion of the 8-acre (3.2-ha) study area, seedling emergence of grasses on individual species plots did not occur until late May 1977. At the end of the first growing season, surviving plants were most numerous on the hay-amended plots and fewest on compost-amended plots, though differences were not great. Data on mean percent frequency followed the same trend as the data on plant density. During the next 5 years, differences in percent frequency between amendment treatments were small (table 23). Mean percent frequency declined on subsoil plots and remained nearly the same on topsoil plots.

Table 23.—Mean combined percent frequency of 10 grass species by soil type and soil amendment treatment, Alton coal field

Year	Topsoil hay[1]	Topsoil compost	Topsoil control	Subsoil hay	Subsoil compost	Subsoil control
1977	43	39	40	43	34	39
1978	75	77	73	76	71	75
1979	78	80	79	71	58	71
1980	76	75	77	68	54	62
1981	70	79	79	65	59	63
1982	71	78	74	61	56	58

[1] Percent frequency on hay-amended plots does not include the smooth brome component except in 1977.

Data on yield were first obtained in the third growing season, 1979, and are shown in table 24. Yields were significantly higher on topsoil plots than on subsoil plots in 1979 and 1980 (fig. 29). No statistical analyses were made in 1981 and 1982, but yields remained considerably higher on topsoil plots than on subsoil plots through the sixth year.

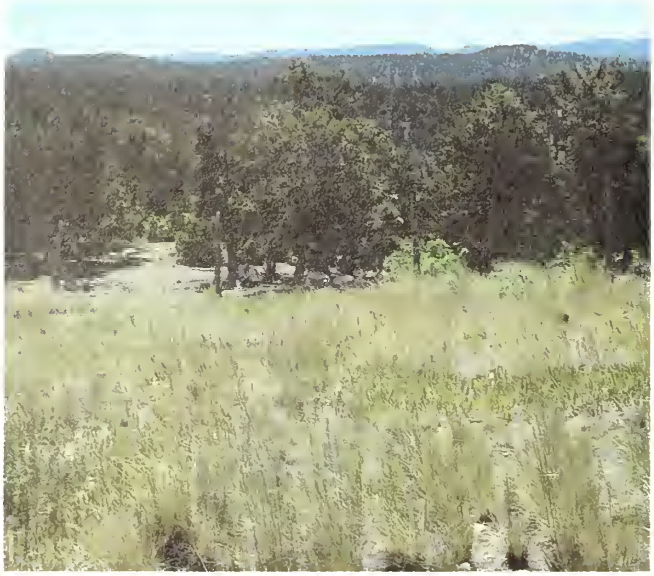


Figure 29a.—Growth of perennial grasses on an area where topsoil was replaced following topsoil removal and deep ripping of the subsoil.

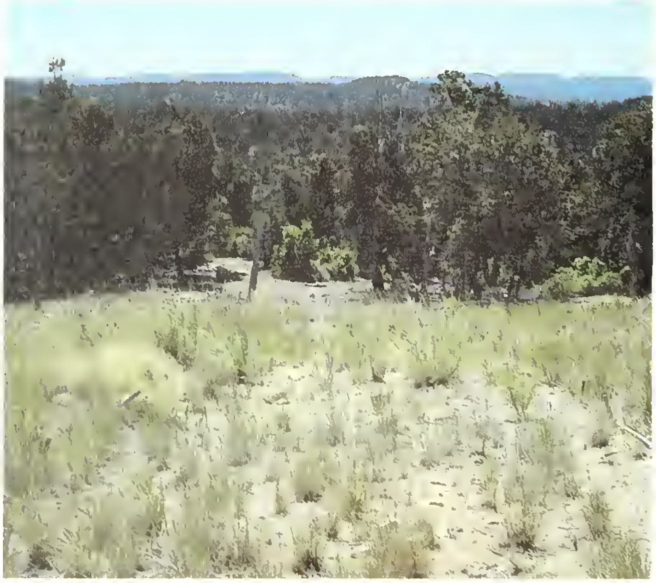


Figure 29b.—Growth of perennial grasses on an area where topsoil was not replaced. July 15, 1982.

No differences in yield between soil amendment treatments were found in 1979 or 1980. In 1981 and 1982, yield differences between amendments were small on topsoil plots. However, yields on hay-amended subsoil plots did appear appreciably higher than yields on compost-amended and control subsoil plots (fig. 30 and table 24).

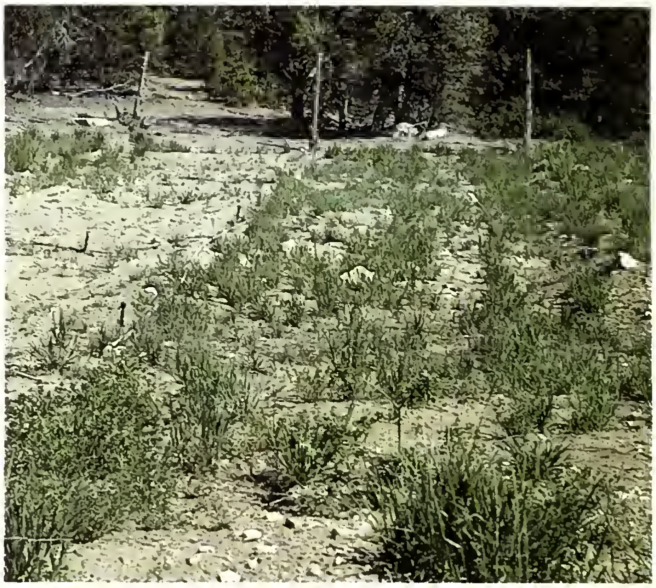


Figure 30.—Comparison of perennial grass growth on an area of subsoil material that was amended with hay (center) and on an area of subsoil that was not amended (left). May 1979.

Table 24.—Mean combined yields (lb/acre, air–dry) of 10 species of grasses by soil type and soil amendment treatment, Alton coal field

Year	Topsoil hay[1]	Topsoil compost	Topsoil control	Subsoil hay	Subsoil compost	Subsoil control
1979	916	928	792	655	344	274
1980	1,068	904	854	478	415	407
1981	490	476	501	311	234	220
1982	973	979	866	807	513	472

[1] Yields on hay–amended plots include the smooth brome component.

Soil samples collected at the end of the sixth growing season indicated little difference in the physical and chemical properties of soil amended with hay or composted bark, and nonamended soil (appendix table 58). Topsoil did exhibit a higher saturation percentage and a higher cation exchange capacity than subsoil.

Overall, the several perennial grass species were better distributed on the topsoiled area than on the subsoil area (table 23).

The value of organic soil amendment may depend on the quality of the soil material available for use as surface soil. In this study, a grass hay soil amendment tended to increase productivity of grasses when applied to subsoil, but not when applied to topsoil.

Performance of Grass Species

On the individual grass species plots, streambank wheatgrass and crested wheatgrass were highest in percent frequency and density at the end of the first year (table 25). During the subsequent 5 years, all species except smooth brome showed some decrease in percent frequency of occurrence.

Table 25.—Mean percent frequency of 10 grass species on 10-ft by 15-ft plots in each year, 1977 through 1982, Alton coal field

Species symbol[1]	1977	1978	1979	1980	1981	1982
AGCR	[2]91(5.8)	91	92	84	72	81
AGEL	81(4.5)	86	78	71	66	64
AGIN	77(4.4)	69	72	67	57	57
AGIN^2	89(4.8)	86	82	77	78	78
AGRI	93(6.0)	85	87	80	78	79
AGSM	57(3.2)	41	50	54	59	52
AGTR^2	86(4.1)	70	77	74	76	76
BRIN	82(4.5)	80	82	84	94	97
ELCI	50(3.1)	35	28	25	36	25
ELJU	82(5.0)	84	77	74	68	54
Mean	78	73	72	69	68	66

[1] See appendix table 69 for plant symbol key.

[2] Values in parentheses show mean density in number of plants per square foot.

By the third year, when yield was first sampled, five of the six "introduced" species produced more herbage than any of the four "native" species (table 26). Only the introduced Russian wildrye exhibited a mean yield as low as the native species.

Table 26.—Mean yield (lb/acre, air-dry) of 10 grass species, on 10-ft by 15-ft plots, in each year from 1979 through 1982, Alton coal field

Species symbol[1]	1979	1980	1981	1982
AGCR	815	882	357	471
AGEL	932	727	653	849
AGIN	360	641	233	715
AGIN^2	980	791	298	530
AGRI	425	541	209	320
AGSM	172	243	110	152
AGTR^2	678	624	359	536
BRIN	680	698	271	586
ELCI	470	558	756	1,927
ELJU	360	454	172	203
Mean	587	616	342	629

[1] See appendix table 69 for plant symbol key.

Yield of most species peaked in the fourth year, 1980, which was a good growing season because of excellent overwinter soil moisture storage. That year, one of the native species, beardless bluebunch wheatgrass, approached the yield of the introduced species. However, crested wheatgrass, intermediate wheatgrass, and tall wheatgrass were still the leading herbage producers.

In the fifth year, 1981, six of the 10 grass species showed a mean decrease in yield of just over 60 percent from the previous year. The 1981 growing season was a poor one in the Alton vicinity. The only species to show an increase in yield was Great Basin wildrye, individual plants of which continued to increase in size.

By the sixth year, beardless bluebunch wheatgrass and Great Basin wildrye (native species) were two of the top three species in terms of yield. The best yielding introduced species was tall wheatgrass.

The larger sized bunchgrasses (Great Basin wildrye, tall wheatgrass, and beardless bluebunch wheatgrass) were the highest yielding species after 6 years despite being tenth, sixth, and seventh, respectively, in mean percent frequency of occurrence. Of the five rhizomatous species, three (smooth brome, pubescent wheatgrass, and intermediate wheatgrass) were intermediate in yield, along with crested wheatgrass. By 1982 the continual increase in the spread of smooth brome elevated it to first place in percent frequency. However, this species was only fourth in yield after 6 years. The other two rhizomatous species, streambank wheatgrass and western wheatgrass, ranked third lowest and lowest, respectively. Sodar streambank wheatgrass, normally a sod former, tended to resemble a bunchgrass on these plots. Western wheatgrass has not spread well on this site. The remaining bunchgrass, Russian wildrye, exhibited low yields but remains in reasonably healthy condition.

Adaptability of Grass Species

As on the other study sites on the Alton coal field, generally good seedling emergence of seeded grasses occurred in May 1977 on the 3-acre (1.2-ha) site. By the end of the first growing season, plant growth was best on plots where topsoil had been left in place, followed by the plots of gravelly clay loam subsoil, carbonaceous shale, and silty clay subsoil, in that order. Plant density and mean percent frequency were highest on plots of gravelly clay subsoil. During the next 5 years, mean percent frequency of the 12 grass species increased on all soil materials except the silty clay subsoil (table 27).

Table 27.—Combined mean percent frequency of all grass species on four different soil materials, Alton coal field

Year	Sandy loam topsoil	Gravelly clay loam subsoil	Carbonaceous shale overburden	Silty clay subsoil
1977	55	59	43	48
1978	62	60	44	34
1979	73	64	40	18
1980	77	62	44	30
1981	73	65	54	40
1982	73	63	55	41

However, there was no change on the sandy loam topsoil plots and clay loam subsoil plots after the third year.

Combined mean yields of the 12 grasses on the four soil materials fluctuated from year to year with seasonal growing conditions (table 28). However, yields on the topsoil and clay loam subsoil remained much superior to those on carbonaceous shale overburden and silty clay subsoil, as would be expected from the wide differences in stand density. After 6 years, overall yield and plant size was slightly greater on the clay loam subsoil plots than on sandy loam topsoil.

Table 28.—Combined mean yield (lb/acre, air-dry) of 12 grass species on four soil materials, Alton coal field

Year	Sandy loam topsoil	Gravelly clay loam subsoil	Carbonaceous shale overburden	Silty clay subsoil
1979	1,295	1,135	410	55
1980	677	660	356	134
1981	570	719	247	163
1982	952	1,161	638	388

Table 29 shows mean percent frequency and mean yield of each grass species sown on the study site for each year of the study. Intermediate wheatgrass, tall wheatgrass, and pubescent wheatgrass were definitely superior in herbage production during the first 3 years, although most species appeared reasonably well adapted to the sandy loam topsoil and clay loam subsoil. In the initial year, Great Basin wildrye, western wheatgrass, and the rhizomatous form of crested wheatgrass produced the thinnest stands.

As was the case on the 8-acre (3.2-ha) study site, during the first 3 years, introduced species (except Russian wildrye) produced much more herbage than native species, with the exception of Great Basin wildrye.

With the passage of time, all four of the native species improved, either in terms of frequency of occurrence or in herbage yield. Great Basin wildrye, because of its large stature, became the highest yielding species by the fifth year, and by the sixth year only tall wheatgrass, among introduced species, outyielded the native beardless bluebunch wheatgrass.

Three bunchgrasses—crested wheatgrass, tall wheatgrass, and Russian wildrye—decreased in frequency of occurrence over the 6 years. On the other hand, four of the highly rhizomatous species significantly increased in frequency (table 29). After 6 years, none of the 12 species seemed in any danger of dying out.

One reason for low yields exhibited by western wheatgrass may be the preference seemingly shown for it by the few rabbits that found their way under the exclosure fence. Rabbit use of western wheatgrass was especially noticeable during the 1981 growing season.

Bioassay of Four Soil Materials

In a bioassay study, the four soil materials on which individual grass species were tested (sandy loam topsoil, clay loam subsoil, silty clay subsoil, and carbonaceous shale overburden) were compared as growing media. No significant difference in the seedling emergence of either tall wheatgrass or smooth brome could be demonstrated between the four types of soil material. Overall seedling emergence was 98 percent for tall wheatgrass and 67 percent for smooth brome.

Analyses of variance and mean separation tests yielded evidence at the 0.05 percent level that plants grown on the four soil materials differed in leaf height after growing 60 days (table 30). Smooth brome was significantly larger when grown on sandy loam topsoil than when grown on any of the other three soils. Tall wheatgrass reached significantly larger size on sandy loam topsoil than on any other soil, and was also larger on carbonaceous shale overburden than on clay loam or silty clay subsoils.

There was no significant difference in growth (as indicated by leaf height) of either species resulting from the addition of composted conifer bark or ammonium nitrate fertilizer.

Table 29.—Mean percent frequency (Fr.) and mean yield (Yld.) (lb/acre, air-dry) of 12 species of grass grown on four soil materials, Alton coal field

Species	1977	1978	1979		1980		1981		1982	
symbol[1]	Fr.	Fr.	Fr.	Yld.[2]	Fr.	Yld.	Fr.	Yld.	Fr.	Yld.
AGCR	68	66	55	675	54	402	58	351	48	520
AGCR(r)	37	48	45	480	43	337	36	309	34	520
AGEL	56	58	52	1,610	58	1,071	56	722	49	1,730
AGIN	45	52	50	44	43	279	42	332	46	1,230
AGIN[2]	66	48	62	1,820	66	704	80	402	82	660
AGRI	57	64	54	490	58	338	68	343	69	470
AGSM	36	41	45	310	63	203	82	212	86	310
AGSP x AGRE	54	42	41	565	40	248	49	390	46	650
AGTR[2]	58	51	50	1,005	64	380	70	323	84	640
BRIN	64	69	61	540	73	697	85	397	88	640
ELCI	20	19	30	750	34	618	28	1,047	32	1,590
ELJU	53	41	49	230	44	204	49	265	34	450
Mean	51	50	50	743	53	457	59	424	58	784

[1] See appendix table 69 for plant symbol key.

[2] Yield was first sampled in 1979.

Table 30.—Mean leaf height[1] (inches) of two grass species grown in the greenhouse on four soil materials from the Alton 3-acre study site

Species	Sandy loam topsoil	Carbonaceous shale overburden	Clay loam subsoil	Silty clay subsoil
Tall wheatgrass	8.2	4.9	3.5	3.4
Smooth brome	5.9	2.5	1.8	1.5

[1] Means underscored by the same line are not significantly different at the 0.05 percent level.

The soils occurring on the 8-acre (3.2-ha) and 3-acre (1.2-ha) study sites were relatively similar in terms of salinity and sodicity (appendix tables 58 and 59). If soil materials of greater salinity or sodicity are encountered in future revegetation efforts on the Alton coal field, greater attention will be necessary to differences in salt tolerance among plant species. Moxley and others (1978) found that 'Jose' tall wheatgrass and 'Critana' thickspike wheatgrass were somewhat more salt tolerant as seedlings than either of three certified varieties of western wheatgrass—'Rosana,' 'Arriba,' or 'Barton.' However, yield of all five decreased rapidly as electrical conductivity of the soil solution increased beyond 4 mmhos/cm.

Establishment and Longevity of Plant Species

Chemical and physical analyses (appendix table 59) showed that other than being low in available nitrogen, none of the three topsoils or the carbonaceous shale overburden in this study were unsuited to plant growth. The carbonaceous shale overburden, taken from immediately above a coal seam, was observed to weather quite rapidly to a clay loam texture. Throughout this report it will be referred to as a clay loam. In the first growing season, 1977, Indian ricegrass and crested wheatgrass were the most vigorous of the six grass species on all soils. Several plants of these two species produced seed in 1977.

'Drylander' alfalfa (*Medicago media*) was by far the outstanding plant species on all soils with respect to numbers of seedlings emerging and first season growth. Some plants reached 15 inches (38 cm) in height in 1977, and numerous plants produced seed. Of the other five forb species sown, some vigorous plants of small burnet, gooseberryleaf globemallow, and cicer milkvetch became established. Although arrowleaf balsamroot and Utah sweetvetch seedlings were observed on all study plots in both 1977 and 1978, no balsamroot and only a small number of sweetvetch plants survived.

Fourwing saltbush and winterfat were the only shrub species to survive past the first two seasons. Seedlings of mountain-mahogany, bitterbrush, and green ephedra were evident in June 1978 on all plots, but none survived.

After 5 years, crested wheatgrass remained the dominant grass species on all soils. Western wheatgrass increased in density, but tall wheatgrass density decreased on all soils.

Tables 31 and 32 show the mean number of plants per square yard and the mean percent ground cover at intervals between 1978 and 1981. Number of grasses and shrubs declined on all four soil materials between 1978 and 1981. Number of forbs declined on all soil materials except silty clay, where alfalfa numbers increased. Thus, after 5 years, the decrease in plant numbers on plots of clay loam (shale overburden), sandy loam topsoil over clay loam, and loam topsoil over clay loam resulted in similar total plant density (table 31). Although plant density on plots of silty clay topsoil placed over clay loam was less than on the other soil materials (table 31),

Table 31.—Comparison of mean number of plants per square meter[1] after 2, 3, and 5 years on four soil material combinations; data pooled from fertilized and nonfertilized plots

Species symbol[2]	Clay loam (40")			Three topsoils (10") over 30" clay loam								
				Sandy loam			Loam			Silty clay		
	1978	1979	1981	1978	1979	1981	1978	1979	1981	1978	1979	1981
AGCR	20.7	14.6	11.4	27.0	24.9	19.8	21.9	17.6	13.4	6.8	3.8	4.8
AGEL	3.9	2.6	1.0	4.7	3.4	1.0	6.1	6.4	2.0	.9	1.1	.8
AGSM	1.0	.4	1.6	.7	1.1	3.0	2.9	2.6	8.1	.9	.2	1.1
ELJU	4.4	1.5	.8	5.2	1.3	.8	5.0	2.6	1.8	1.6	1.8	.9
ORHY	.6	—	—	.1	.1	—	.4	—	—	.6	—	—
Total	30.6	19.1	14.8	37.7	30.8	24.6	36.3	29.2	25.3	10.8	6.9	7.6
MEME	17.7	17.4	17.6	10.8	11.8	10.2	8.9	10.3	9.4	5.9	10.6	14.7
SAMI	5.8	3.0	.1	4.2	1.0	.1	3.3	2.0	.1	2.0	1.6	.6
ASCI	6.1	1.2	.2	1.8	.1	—	1.6	.3	—	1.7	.8	.3
SPGR	.4	—	.1	.2	.1	—	.3	—	—	—	—	—
Total	30.0	21.6	18.0	17.0	13.0	10.3	14.1	12.6	9.5	9.6	13.0	15.6
ATCA	1.2	.9	.7	.8	.4	—	.6	.2	—	1.5	.8	.7
CELA	3.1	.6	.1	5.4	.1	—	1.3	.1	—	1.5	.6	—
Total	4.3	1.5	.8	6.2	.5	—	1.9	.3	—	3.0	1.4	.7
Total	64.9	42.2	33.6	60.9	44.3	34.9	52.3	42.1	34.8	23.4	21.3	23.9

[1] Values shown for individual species are means of four replications.
[2] See appendix table 69 for plant symbol key.

Table 32.—Mean percent ground cover by plant class on four soil material combinations after 1, 2, 3, and 5 years. Data are pooled from fertilized and nonfertilized plots

Plant class		Clay loam (40″)	Three topsoils (10″ over 30″ clay loam)		
			Sandy loam	Loam	Silty clay
Grasses	1977	0.7	0.3	0.1	0.1
	1978	6.7	8.8	19.3	2.0
	1979	17.2	27.1	34.0	7.6
	1981	11.0	24.7	24.2	5.7
Forbs	1977	2.9	9.4	1.6	2.2
	1978	16.0	31.8	13.6	17.0
	1979	32.2	32.8	20.5	40.0
	1981	13.2	8.3	5.0	13.4
Shrubs	1977	1.2	1.3	.1	.1
	1978	6.2	6.1	1.0	3.9
	1979	9.5	6.0	1.2	4.0
	1981	1.9	.3	.2	2.2
Total cover[1]	1977	4.8	11.0	1.8	2.4
	1978	28.9	46.7	33.0	22.9
	1979	58.9	65.9	55.6	51.6
	1981	26.0	33.4	29.6	21.2

[1] Total cover shown is slightly more than true percent ground cover because of overlap among plants. Values shown in the table are means of four replications.

statistical analyses indicated the difference was only significant on the nonfertilized half of the study plots (fig. 31).

After 5 years total plant density had decreased on all soil materials except the silty clay plots, on which the number of alfalfa plants had increased. Percent ground cover had also decreased to roughly half of what it had been after the first 3 years (table 32).

Yields of all classes of vegetation declined between 1979 and 1981. Total yield in 1981 ranged from 29 percent of the 1980 yield on silty clay plots to 37 percent of the 1980 yield on loam plots (table 33).

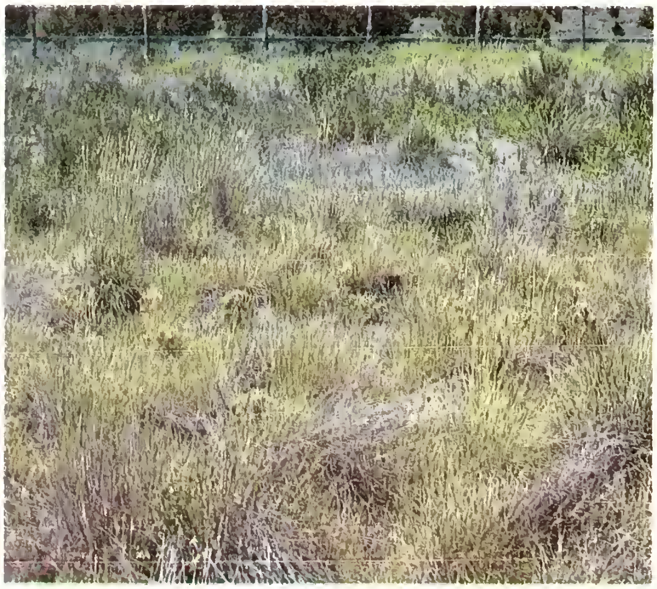


Figure 31a.—Fertilized portion of plot of carbonaceous shale overburden covered by 10 inches of sandy loam topsoil in the sixth year following seeding.

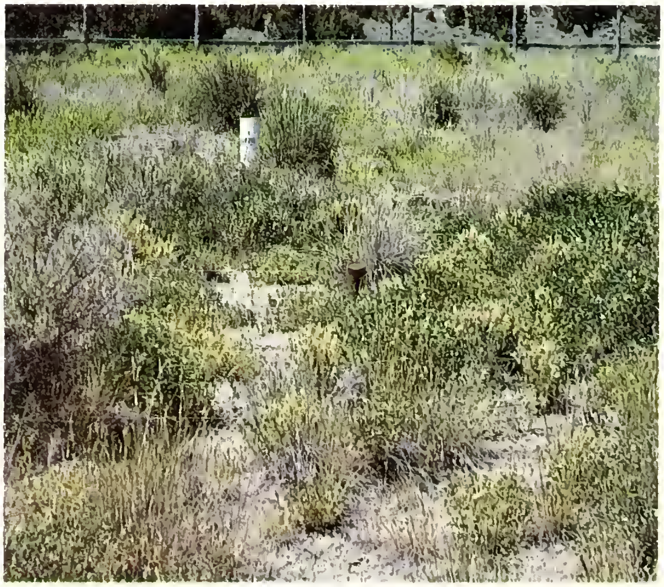


Figure 31b.—Fertilized portion of plot of carbonaceous shale overburden covered by 10 inches of silty clay topsoil in the sixth year following seeding.

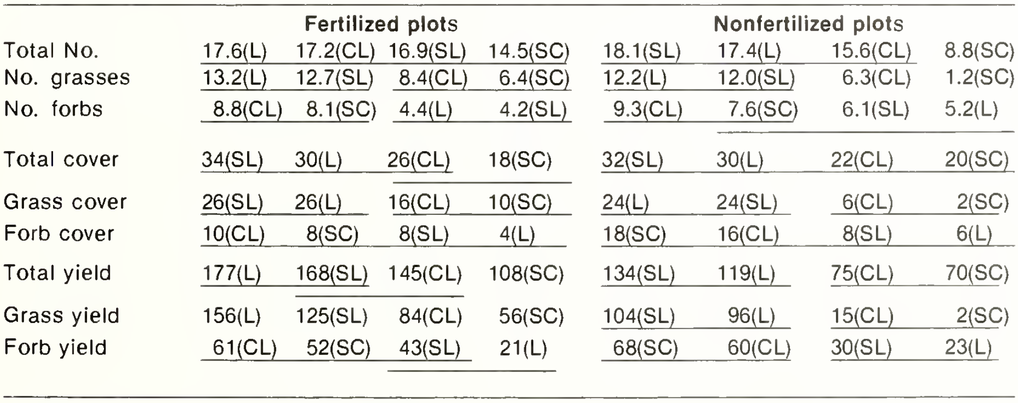
Table 33.—Mean herbage yield (grams/m^2 air–dry) on fertilized (F) and nonfertilized (NF) plots of four soil material combinations, for third, fourth, and fifth years, Alton coal field

			Three topsoils (10") over 30" clay loam					
Vegetation	Clay loam (40")		Sandy loam		Loam		Silty clay	
class	F	NF	F	NF	F	NF	F	NF
1979								
Grasses	228	29	224	141	251	250	101	8
Forbs	80	253	148	338	100	190	132	338
Shrubs	28	51	15	44	7	4	6	10
Total	336	333	387	523	358	444	239	356
1980								
Grasses	160	22	267	227	293	255	132	4
Forbs	208	282	277	225	107	134	222	238
Shrubs	4	5	0	4	0	4	3	12
Total	372	309	553	456	400	393	357	255
1981								
Grasses	84	15	125	104	156	96	56	2
Forbs	61	60	43	30	21	22	53	68
Shrubs[1]	—	—	—	—	—	—	—	—
Total	145	75	168	134	177	118	109	70

[1]Shrubs contributed so little yield in 1981 that they were not sampled.

Figure 32 shows the results of tests for significant differences between means, for plant numbers (density), percent ground cover, and herbage yield. The primary reason for the large decrease in total yield between 1980 and 1981 was the drastic reduction in yield of alfalfa, an average of 80 percent reduction for all soils. While no data were taken from these plots in 1982, we observed that alfalfa continued to decline in vigor and most likely in number of surviving plants. Subjective evaluation of the appearance of vegetation on these plots at that time pointed to a slight overall superiority in color and vigor of vegetation on plots of sandy loam topsoil underlain by clay loam (carbonaceous shale overburden).

Appendix tables 59 and 60 show some chemical and physical properties of each of the four soil materials used in this phase of the research at Alton. Over 6 years the salinity of all four soil materials declined (table 34). Sodicity, as indicated by the sodium adsorption ratio (SAR), steadily decreased on plots of silty clay and remained low on the other three soil materials. Even in the upper portion of the carbonaceous shale overburden (clay loam) that was covered with sandy loam, loam, or silty clay topsoil, the SAR remained low. Changes in soil properties can be expected with the passage of time. For example, some of the soil properties shown in appendix tables 59 and 60 for the carbonaceous shale soil



	Fertilized plots				Nonfertilized plots			
Total No.	17.6(L)	17.2(CL)	16.9(SL)	14.5(SC)	18.1(SL)	17.4(L)	15.6(CL)	8.8(SC)
No. grasses	13.2(L)	12.7(SL)	8.4(CL)	6.4(SC)	12.2(L)	12.0(SL)	6.3(CL)	1.2(SC)
No. forbs	8.8(CL)	8.1(SC)	4.4(L)	4.2(SL)	9.3(CL)	7.6(SC)	6.1(SL)	5.2(L)
Total cover	34(SL)	30(L)	26(CL)	18(SC)	32(SL)	30(L)	22(CL)	20(SC)
Grass cover	26(SL)	26(L)	16(CL)	10(SC)	24(L)	24(SL)	6(CL)	2(SC)
Forb cover	10(CL)	8(SC)	8(SL)	4(L)	18(SC)	16(CL)	8(SL)	6(L)
Total yield	177(L)	168(SL)	145(CL)	108(SC)	134(SL)	119(L)	75(CL)	70(SC)
Grass yield	156(L)	125(SL)	84(CL)	56(SC)	104(SL)	96(L)	15(CL)	2(SC)
Forb yield	61(CL)	52(SC)	43(SL)	21(L)	68(SC)	60(CL)	30(SL)	23(L)

Figure 32.—Results of Duncan's multiple range tests (P = 0.05) on mean values of plant numbers (no./m^2), percent ground cover, and herbage yield (g/m^2), on plots of four different soil materials after 5 years, Alton coal field. Mean separation tests were not made on total plant numbers on fertilized plots, total cover on nonfertilized plots, or forb cover on nonfertilized plots. Analyses of variance tests showed no significant differences in those sets of data. Means underlined are not significantly different. SL = sandy loam, L = loam, CL = clay loam, and SC = silty clay.

Table 34.—Electrical conductivity (ECe, mmhos/cm) and sodium adsorption ratio (SAR) of soil materials on the Utah International cooperative study site,[1] Alton coal field

	Soil material							
	Clay loam		Sandy loam		Loam		Silty clay	
Year	ECe	SAR	ECe	SAR	ECe	SAR	ECe	SAR
1976	3.3	0.5	0.6	0.8	1.1	0.6	0.6	3.1
1978	7.8	1.0	2.3	1.0	1.7	1.0	1.0	2.0
1979	3.0	.4	.5	.7	.8	.4	.5	.7
1980	1.1	.3	.3	.7	.4	.7	.3	.6
1981	.4	.7	.5	.5	.5	.6	.3	.8
1982	.9	.3	.4	.3	.4	.6	.4	.4

[1] Data are for composite soil samples from the 4- to 8-inch depth.

materials are different despite the samples being taken from the same strata of shale, at the same location. However, the results of analyses shown in appendix table 59 were from samples taken from the shale immediately after it was uncovered by the bulldozer, whereas the results shown in appendix table 60 were obtained from the surface 8 inches (20 cm) of the shale after being exposed to weathering for 6 years.

The soil moisture status on all plots of the four soil materials was monitored throughout most of each of the first four growing seasons. Throughout these four growing seasons, vegetation on the study plots exhibited little moisture stress except for brief periods during August and September. Two factors may have been responsible for this: (1) overwinter precipitation was above average every year, after the dry winter of 1976 to 1977; and (2) the 30 inches (76 cm) of carbonaceous shale used as a foundation for the soil material combinations retained soil moisture well. Soil moisture data showed that summer rains rarely replenished the soil moisture content of any soil material to a depth of 8 inches.

Color and textural differences of the four soil materials had only a small effect on soil temperatures at the 8-inch (20-cm) depth. Temperature of the reddish-colored, sandy loam topsoil was often higher during sunny weather than the temperature of the other three soils. Since sandy soils dry more rapidly than other soils, it would be expected that temperatures in sandy loam would fluctuate more rapidly than temperatures in heavier textured soils.

Soil temperatures at depths of 18 inches (46 cm) and 30 inches (76 cm) were remarkably similar during the 4 years of observation. Figure 33 illustrates the course of soil temperature at depths of 8, 18, and 30 inches throughout the growing season.

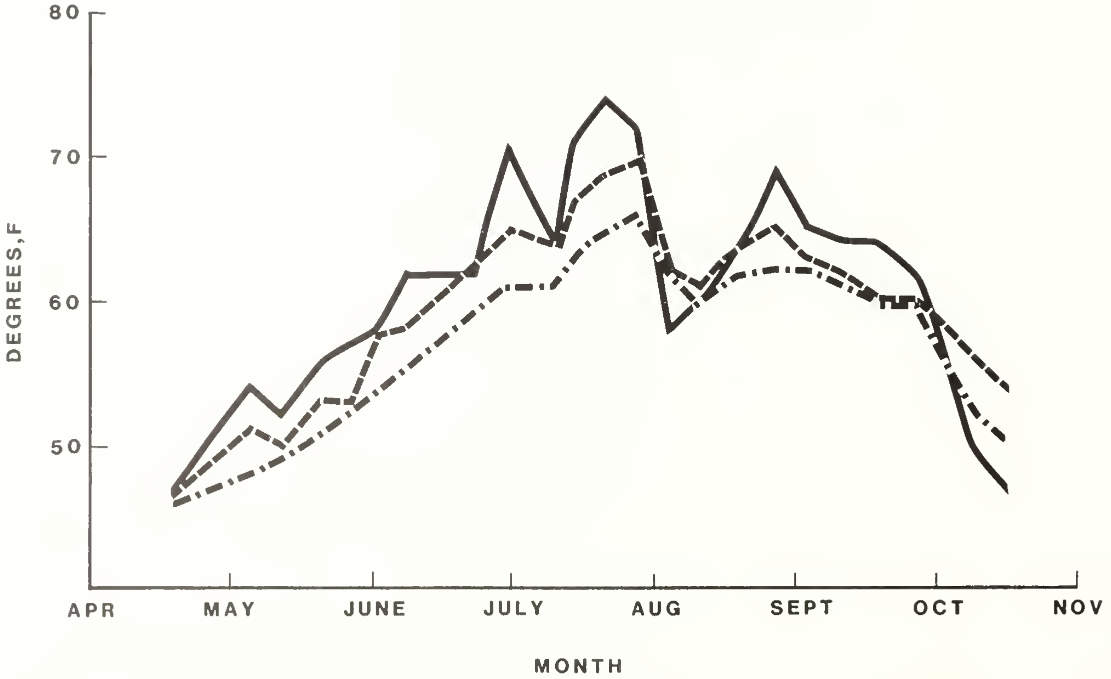


Figure 33.—At the Utah International cooperative study site, soil temperature at 8, 18, and 30 inches depth in loam topsoil (10 inches) placed over carbonaceous shale overburden during growing season of 1979.

Adaptability of Shrub and Forb Species

Of the 28 shrub and forb species planted on the drill pad site, adjacent to the 8-acre (3.2-ha) study site, 22 exhibited 90 percent or greater first-year survival. Table 35 shows the mean percent survival and mean height and diameter of all the species planted on the drill pad site after 6 years.

Most species exhibited good survival. *Astragalus globiceps*, from Turkey, gradually died out over the first 4 years. The only other species to fail completely was the accession of fourwing saltbush from New Mexico. Of the fourwing saltbush plants 98 percent survived the first season and grew to an average height of 15 inches (38 cm). However, many of the plants were in poor condition in spring 1978, and by spring 1979 only two of the original 40 plants were alive. All were dead by the end of the fourth year. Because nearly all mortality of fourwing saltbush occurred during the winter (minimum temperature in January 1979 reached −22° F, or −30° C), this accession apparently lacked winter hardiness. In 1981, an accession of fourwing saltbush from Johnson Canyon, 17 miles (27 km) south of the study area, was used to replace the original planting.

Table 35.—Mean percent survival and mean height and diameter of shrub and forb species 6 years after planting at the 8-acre study site, Alton coal field

Species symbol[1]	Mean survival	Mean height	Mean crown diameter
	Percent	*Inches*	
AMFR	79	9*	12
AMUT	80	24*	24
ARNO	85	15*	20
ARTR	85	26*	36
ASGL**	0	—	—
ATCA	[2]90	5	4
BEFR	90	17	17
CAAR	72	28*	31
CECU	95	24	31
CELA	50	14*	15
CELE	90	27	25
CEMO	95	26	25
CHNA	90	31*	37
COST	90	27*	29
CUAR	60	44	28
ELAN	92	47	44
EPVI	100	20*	19
HEBO**	88	22*	24
KOPR	92	24*	19
LOTA	90	22*	22
PERA	58	17	17
POFR	55	16*	16
PRVI	98	34*	25
PUTR	95	23*	30
RHTR	98	25*	33
RIAU	95	38*	37
ROWO	100	30*	34
SACE	68	18	19
SHRO	15	16	16
SPGR**	18	4*	8

[1] See appendix table 69 for plant symbol key.
[2] All original ATCA died. A different accession was planted in 1981.
*These species produced some seed in 1 or more years.
**Forbs.

Many of the species produced seed one or more times during the first 6 years (table 35). Wild rose exhibited good vegetative reproduction, with some root suckers emerging up to 9 ft (2.7 m) away from the parent plant. Prostrate summercypress produced numerous seedlings, many of which became established at distances of 6 to 10 ft (1.8 to 3 m) from parent plants. Piute cypress suffered some degree of winter damage from cold temperatures nearly every winter, yet several plants continued to make excellent growth, with a maximum height of 73 inches (185 cm). Gooseberryleaf globemallow exhibited excellent vigor for the first 3 years, then declined in numbers and vigor through the sixth year.

In addition to damage from winter temperatures, several species exhibited some dieback from late spring or summer frosts. Most susceptible to frost damage was the succulent growth of elderberry, Siberian peashrub, Fremont barberry, rose, skunkbush, Tatarian honeysuckle, milkvetch, globemallow, and Piute cypress. Tent caterpillars caused severe defoliation of chokecherry in 1981, and lesser damage to rose, bitterbrush, and curlleaf cercocarpus.

After 6 years, shrubs on this site were competing quite severely with one another for space and soil moisture because of the original plant spacing of 3 by 3 ft (0.9 by 0.9 m). Several of the most vigorous species are shown in figures 34 through 39.

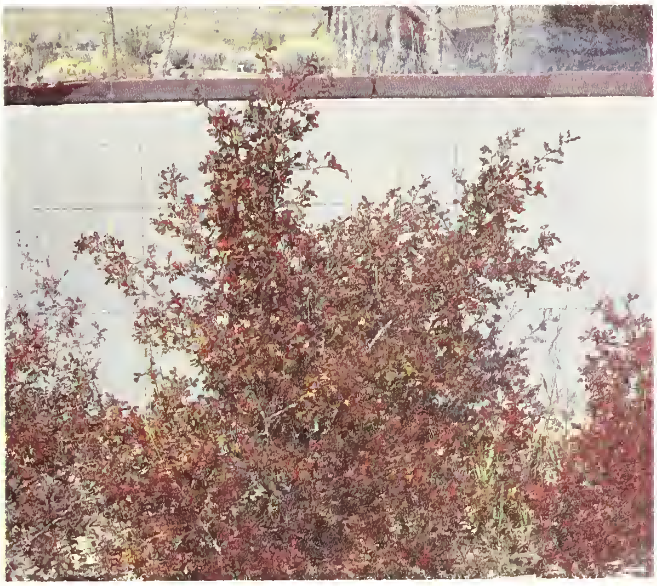


Figure 34.—Six-year-old Rosa woodsii, *established from container-grown planting stock on the Alton 8-acre study area. September 1982.*

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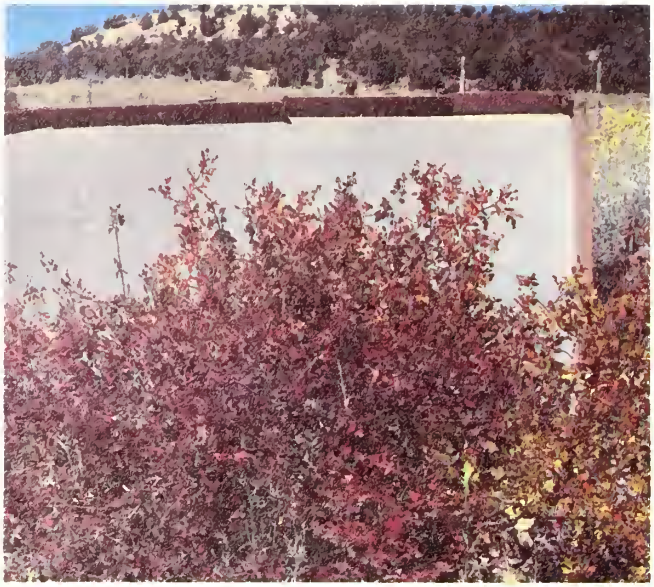

Figure 35.—Six-year-old Rhus trilobata, *established from container-grown planting stock on the Alton 8-acre study area. September 1982.*

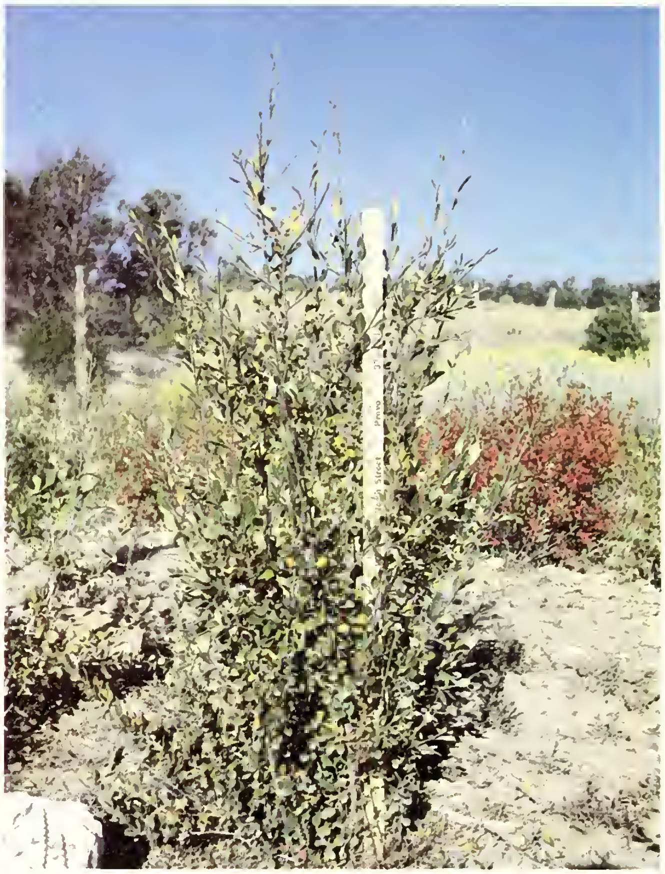

Figure 37 —Five-year-old Cercocarpus montanus *established from container-grown planting stock on the Alton 8-acre study area. September 1981.*

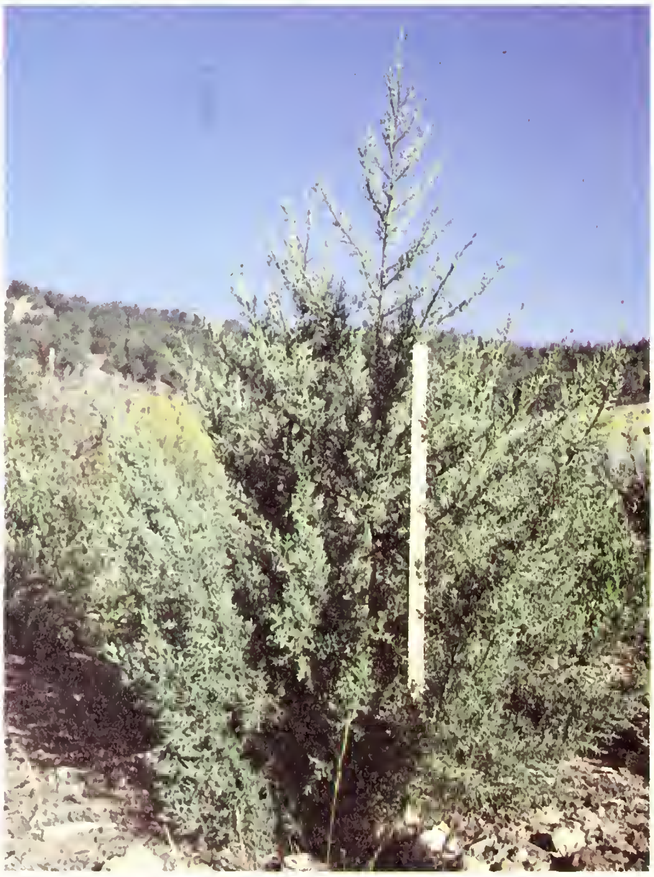

Figure 36.—Excellent young Cupressus nevadensis *tree near the end of the fifth growing season on the Alton 8-acre study area. September 1981.*

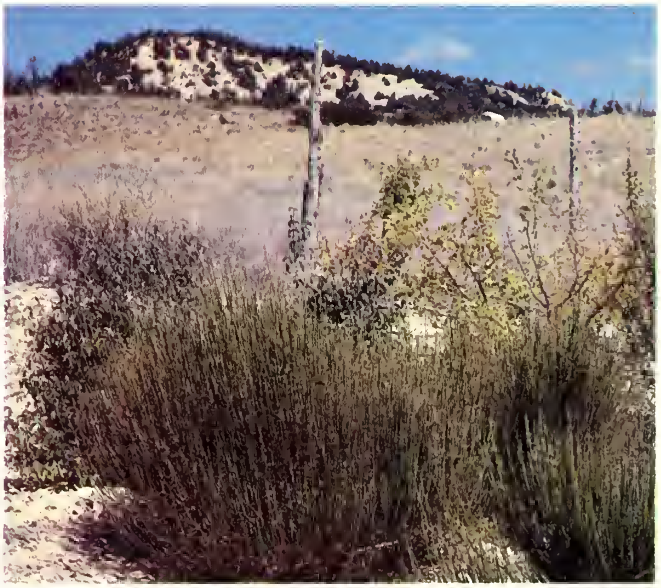

Figure 38.—Six-year-old Ephedra viridis *established from container-grown planting stock on the Alton 8-acre study area. September 1982.*

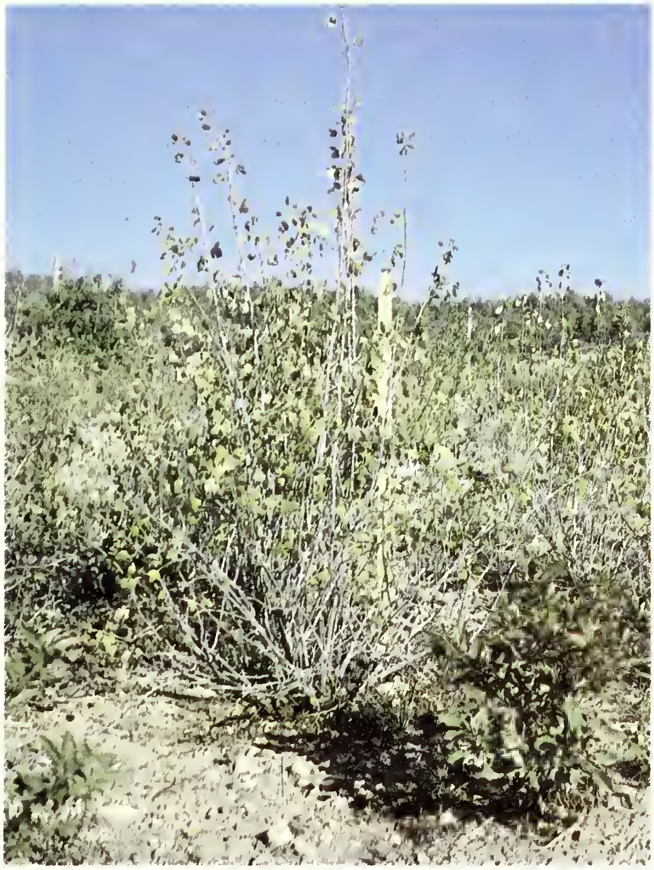

Figure 39.—Five-year-old Ribes aureum *established from container-grown planting stock on the Alton 8-acre study area. September 1981.*

Shrub Plantings of 1980

Survival of shrubs and herbaceous species planted in May 1980 was excellent even though no supplemental water was applied. Table 36 shows the mean percent survival and the mean height and diameter of the 27 accessions at the end of the third growing season. Several mountain-mahogany plants were killed by deer browsing, and one rabbitbrush, one globemallow, and three winterfat plants were killed by foraging ants. Much deer use in this area occurs during the growing season. Species favored by deer were cercocarpus, penstemon, cliffrose, skunkbush, desert bitterbrush, Utah sweetvetch, rose, hybrid poplar, Utah serviceberry, velvet ash, chokecherry, and Gambel oak.

Although the accessions of globemallow used appear to be short-lived, a number of young plants were observed near the original plants. At least a dozen species produced seed by the second or third growing seasons (table 36). Most of the plant species tested on this site were growing reasonably well after 3 years. A better assessment of the potential of each species can be made after several more years.

Table 36.—Mean percent survival, mean height, and mean diameter of 29 accessions of plants 3 years after planting, Alton coal field

Species symbol[1]	Mean survival	Mean height	Mean crown diameter
	Percent	*Inches*	
ACLA	100	26*	34
AMUT	90	10	13
ARFI	75	36*	42
CELE[2]	95	14	28
CEBE	70	12	13
CELA	68	10*	16
CEMO	75	8	10
CEPA	90	23*	28
CHNA	95	35*	48
COST	100	14	16
CUNE	90	24	20
ERCO	95	16*	23
FAPA	85	28*	28
FRVE	90	12	13
HEBO	90	12*	18
HIJA	94	16*	15
JUHO	100	7	11
PEVE	100	22*	22
POPZ	90	18	24
PRVI	75	6	5
PUGL	95	13	19
QUGA	85	8	6
RHTR	100	22	26
ROWO (Montana)	95	26	31
ROWO (Alton)	100	18	22
SPCO	55	12*	20
SPPA	45	17*	17
STCO	89	16*	10
YUCCA	100	9	10

[1] See appendix table 69 for plant symbol key.

*These species produced some seed in 1 or more years.

Fourwing Saltbush Ecotypes

First-season survival of 20 ecotypes of fourwing saltbush was 100 percent except for one ecotype that lost two plants as a result of soil erosion. Maximum height among ecotypes ranged from 8 to 22 inches (20 to 56 cm), and maximum crown diameter ranged from 7 to 21 inches (18 to 53 cm).

With the exception of a single plant of the Adrian, Oreg., ecotype, all mortality in the first winter season, 1980 to 1981, occurred among ecotypes from south of 34° N latitude. Among those ecotypes, percentage of mortality was: Guaymas (Mexico), 87 percent; Yuma, 40; Tucson, 27; and Joshua Forest, 27. By spring 1982, all plants of the Yuma and Guaymas ecotypes had died because they lacked winter hardiness.

Table 37 shows mean percent survival, mean height, and mean diameter of each ecotype at the end of the

Table 37.—Mean percent survival, mean height, and mean diameter of 20 ecotypes of *Atriplex canescens* after three growing seasons, Alton coal field

Ecotype source	Mean survival	Mean height	Mean crown diameter
	Percent	*Inches*	
Holbrook, AZ	100	37	50
Tuba City, AZ	93	37	46
Tucson, AZ	47	25	17
Yuma, AZ	0	—	—
Yuma (35 E.), AZ	87	27	20
Joshua, CA	13	18	21
Delta, CO	100	40	47
Guaymas, Mexico	0	—	—
Tularosa, NM	100	37	35
Bernalillo, NM	93	38	56
Adrian, OR	93	26	37
Nyssa, OR	100	32	42
Excel Canyon, UT	100	36	43
Sanpete Co., UT	100	38	50
Huntington, UT	[1]80	23	37
Jericho, UT	100	47	44
Jericho, UT (gigas)	100	49	42
Johnson Canyon, UT	100	39	47
Myton, UT	100	34	42
Douglas, WY	100	17	25

[1] Only mortality was caused by soil erosion.

third growing season. Growth rate was excellent for several of the ecotypes (fig. 40). Considerable difference in morphologic features was apparent, especially in leaf size, leaf shape, and branching habit.

The recent release by the U.S. Department of Agriculture of the certified variety 'Rincon' fourwing saltbush provides an additional ecotype that should be tested on the soils of the Alton coal field. From the standpoint of climatic criteria, it appears well suited to the Alton area.

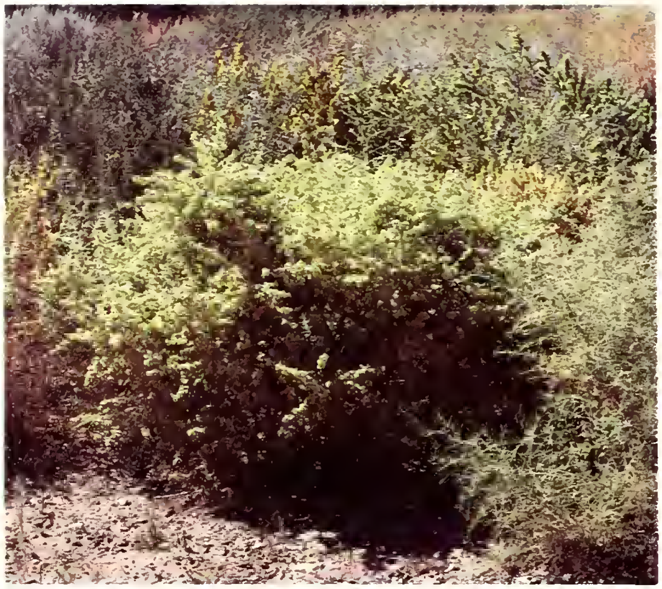

Figure 40.—Three-year-old Atriplex canescens *on the Utah International bulk sample site, Alton study area. The plant in the left foreground is a female plant of the Bernalillo, New Mexico, ecotype. The plant in the right foreground is a male plant of the same ecotype. September 1982.*

Compatibility of Shrub Species with Grasses

All shrub species interplanted on the perennial grass species test plots on the 3-acre (1.2-ha) area showed excellent survival at the end of the first growing season. However, differences in survival among species were evident by the end of the study (table 38).

Table 38.—Number of surviving plants,[1] mean height, and mean crown diameter of 10 shrub species growing on four soil materials at the Alton 3-acre study site at the end of the first and fifth growing seasons

Species		Sandy loam topsoil			Clay loam subsoil			Carbonaceous shale			Silty clay subsoil			Means		
symbol[2]	Year	No.	Ht.	Dia.	No.	Ht.	Dia.	No.	Ht.	Dia.	No.	Ht.	Dia.	No.	Ht.	Dia.
ATCA	1978	22	7	6	22	18	18	22	16	17	22	6	7	22	12	12
	1982	17	13	9	22	40	44	18	26	20	21	24	23	20	27	25
ATBO	1978	20	5	4	22	8	8	22	11	11	22	5	4	22	7	7
	1982	6	4	4	5	18	17	7	3	4	15	7	8	8	7	8
CELA	1978	22	10	6	20	6	4	22	10	7	22	8	4	22	8	5
	1982	14	15	10	9	7	5	6	3	5	13	12	10	10	11	8
CELE	1978	20	7	3	22	4	2	21	4	2	20	5	2	21	5	2
	1982	15	14	12	20	9	9	*	—	—	19	15	14	18	14	13
CEMO	1978	21	9	2	22	7	3	20	7	3	22	10	3	21	8	3
	1982	9	12	9	17	9	9	17	22	17	21	16	14	16	15	13
EPVI	1978	22	7	4	22	7	4	22	7	3	22	7	4	22	7	4
	1982	9	11	7	20	10	5	10	8	4	21	15	10	15	12	7
KOPR	1978	18	4	4	21	14	19	20	7	10	22	4	5	20	7	10
	1982	12	18	10	20	29	24	7	16	15	18	20	16	14	22	17
KOVI	1978	22	10	7	22	12	12	22	7	7	22	6	5	22	9	8
	1982	19	24	12	19	38	23	15	19	19	22	19	16	19	25	17
PUTR	1978	12	8	4	21	7	7	21	7	4	19	7	4	18	7	5
	1982	12	19	22	21	24	28	17	31	39	17	26	38	17	25	32
RHTR	1978	21	9	3	22	8	3	22	7	3	22	9	3	22	8	3
	1982	18	10	9	19	10	10	22	12	14	20	15	20	20	12	13
Mean	1978	20	8	4	22	9	8	21	9	7	22	7	4	21	8	6
	1982	13	15	11	17	21	19	12	18	18	19	17	17	16	18	16

[1] Twenty-two plants of each species were planted on each soil.

[2] See appendix table 69 for plant symbol key.

*All plants lost as a result of being covered by soil sloughing from terrace "high wall."

Fourwing saltbush, skunkbush, villous prostrate summercypress, and curlleaf cercocarpus exhibited the highest overall survival. Nearly all bitterbrush mortality occurred in the first growing season. Bonneville saltbush and winterfat were the least successful species on the four soil materials, although the former species made fairly good growth on the clay loam subsoil.

Table 39 shows the overall survival, mean height, and mean diameter of all shrubs, in competition with each of the grass species. Shrub survival and growth was poorest on plots of two of the most vigorous of the rhizomatous grasses, intermediate wheatgrass and pubescent wheatgrass. Overall, survival of shrubs was higher in competition with bunchgrasses than with rhizomatous grasses.

Judged on the basis of rate of growth over 5 years, bitterbrush, fourwing saltbush, and the two forms of prostrate summercypress were best able to compete with the established grasses.

Shrubs competed more successfully with grass on the clay loam subsoil than on the sandy loam topsoil. Only one shrub species, winterfat, showed both higher survival and better growth on the sandy loam soil. On plots of carbonaceous shale and silty clay subsoil, where grasses were sparse, overall percent survival was higher on the silty clay. However, there was little difference in shrub growth on the two soil materials. Survival of curlleaf cercocarpus, prostrate summercypress, and winterfat was decreased on carbonaceous shale plots as a result of sloughing of the 8-ft (2.4-m) "high walls" on the uphill side of the two terraces.

Characterization of the Microclimate

The automatic data logging system installed at the 8-acre (3.2-ha) study area in May 1979 functioned almost flawlessly. In February 1982 the soil temperature sensor at the 8-inch (20-cm) depth became defective and was not replaced until June 1982. Appendix tables 61 through 64 show summaries of air and soil temperature data obtained over the 40-month study.

The long-term mean annual temperature given by NOAA for the town of Alton is 45.3° F (7.4° C), as shown in appendix table 65. The mean annual temperature, for the 2 years for which we have complete data at the Alton study area was 48.2° F (9.0° C) in 1980, and 50.7° F (10.4° C) in 1981. The mean annual temperature at Alton for those years was 46.4° F (8.0° C) and 47.8° F (8.8° C) in 1980 and 1981, respectively.

In EMRIA Report No. 4-1975 (USDI 1975), the mean number of frost-free days at the town of Alton is given as 120, with a range of 73 to 151. For the years 1938 through 1981, the mean number of frost-free days was 112, with a range the same as that given above. From 1938 to 1981, the average date of last spring frost was June 5 (median = June 4), and the average date of first autumn frost was September 25 (with same median). During the years in which data were obtained at the 8-acre study area, the frost-free period ranged from 141 days in 1980 and 1982, to 156 days in 1979 (appendix table 66). The frost-free period at a height of 12 inches (30 cm) above ground ranged from 96 days in 1982 to 118 days in 1979, and was quite similar to the frost-free

Table 39.—Overall survival, mean height, and mean crown diameter of all shrubs, in competition with 11 different species of grass, after 5 years, Alton coal field.

Competing grass species[1]	All shrubs combined		
	Survival	Mean height	Mean diameter
	Percent	*Inches*	
AGCR	74	17	15
AGEL	68	15	13
AGIN	70	22	21
AGIN[2]	58	14	12
AGRI	75	18	17
AGSM	76	17	16
AGCR(r) or AGSP x AGRE[2]	59	20	19
AGTR[2]	60	14	12
BRIN	69	18	16
ELCI	78	18	18
ELJU	76	18	17

[1] See appendix table 69 for plant symbol key.

[2] The AGSP x AGRE hybrid and the rhizomatous form of AGCR were each planted on half of a single plot on each soil.

period reported for Alton in each year. As mentioned in the description of the Emery microclimate, the "growing season" for most native or introduced plant species is usually of greater length than the frost-free period.

Appendix table 67 shows calculations of the number of growing degree days at the Alton study area from 1979 through 1982. The growing degree days were calculated in the same manner as shown in appendix table 48 for the Emery study area.

The long-term mean precipitation received each month and the annual mean for the town of Alton is shown in appendix table 65. Appendix table 68 shows the precipitation received during each month from October 1976 through September 1982 at the town of Alton, and for each month from May 1979 through September 1982 at the Alton study area.

As previously mentioned, the growing season of 1977 was not a good one in which to establish a stand of vegetation by direct seeding. Had it not been for a "wet" May and greater than average rainfall in July, all study areas seeded in autumn 1976 might have remained nearly bare. Since 1953, the months of October through April (the period of soil moisture accumulation) at Alton have typically received approximately 63 percent of the total precipitation for the water year, October 1 to September 30. However, from 1977 to 1978, 1978 to 1979, and 1979 to 1980, considerably above average precipitation was received in the October to April period (table 40). On the other hand, in 3 of the 6 years of our study, less than average amounts of rainfall occurred during the growing season. The 1979 and 1980 water years were unusually wet, with 22.32 and 23.93 inches (567 and 608 mm) of precipitation, respectively.

From 1953 through 1981, there were only five unusually wet years (more than 40 percent greater than average) and two unusually dry years.

Appendix table 66 shows some additional data obtained on microclimatic factors at the Alton 8-acre study area.

Table 40.—Precipitation received (inches) at the town of Alton, Utah, according to periods of the "water year," 1977 through 1982

October 1 to April 30		May 1 to September 30		Total
1976 – 77	2.20	1977	7.72	9.92
1977 – 78	13.79	1978	3.02	16.81
1978 – 79	19.30	1979	3.02	22.32
1979 – 80	15.25	1980	8.68	23.93
1980 – 81	6.02	1981	5.69	11.71
1981 – 82	10.85	1982	7.28	18.13
Long term:	10.36	Long term:	6.02	16.38

CONCLUSIONS AND RECOMMENDATIONS

Based on data obtained and observations made over a 6-year study on the Alton coal field, we reached the following conclusions and recommendations:

1. The incorporation of a grass hay soil amendment into the top 8 inches (20 cm) of restored topsoil (2.5 tons per acre or 5.6 per ha) should increase the initial establishment of grass, legume, and shrub seedlings on severely disturbed sites. However, a hay soil amendment is not recommended when topsoil of satisfactory quality is present, because our studies indicate that within a few years stand density becomes quite similar on amended and nonamended areas. The addition of an organic soil amendment can increase grass establishment and increase production if subsoil material has to be used on the surface of a reclaimed area.

2. Adequate vegetative stand density can be established to protect the soil from erosion on slopes of 15 percent or less by gouging the soil surface followed by broadcast seeding.

3. "Nomad" alfalfa will probably exhibit a gradual decrease in plant numbers following initial establishment in a mixed grass-alfalfa seeding, but should remain a significant contributor to the total herbage yield for at least 6 years.

4. Fourwing saltbush, bitterbrush, and cliffrose are capable of persisting in competition with grasses and legumes on reclaimed sites, although the latter two species cannot be expected to contribute significant amounts of forage until the fifth or sixth year.

5. Winterfat and green ephedra are unsuited for inclusion in seed mixtures used for revegetation in the Alton coal field area because they are poor competitors with perennial grass and legume mixtures.

6. Yield of grasses should be significantly higher on reclaimed areas where topsoil is returned to the area than where local subsoil material is revegetated.

7. "Introduced" species of grass can be expected to outyield "native" species for the first 3 or 4 years following seeding. However, by the fifth or sixth year, well-adapted native species should equal most introduced species in herbage yield.

8. Based on our studies, perennial grass species that appear well adapted to the climate and soils of the Alton coal field are basin wildrye, 'Alkar' tall wheatgrass, 'Whitmar' beardless bluebunch wheatgrass, intermediate wheatgrass, smooth bromegrass, 'Luna' pubescent wheatgrass, 'Fairway' crested wheatgrass, and 'Nordan' crested wheatgrass. The above species are listed in approximate order of highest herbage yield after 6 years. Other species that appear adapted, but are lower yielding species during the first 6 years, are Russian wildrye, 'Rosana' western wheatgrass, and 'Sodar' streambank wheatgrass.

9. Sandy loam topsoil, of the fine-loamy Typic Argiustolls subgroup described as 4008 on page 16 of EMRIA Report No. 4-1975 (USDI 1975), is perhaps the best soil material for use on the surface of reclaimed areas on the Alton coal field. However, loam topsoil that occurs chiefly in alluvial deposits, and some clay loam subsoil, similar to that used on our 3-acre (1.2-ha) study area, should sustain excellent stands of herbaceous vegetation. Carbonaceous shale overlain by 10 to 12 inches (25 to 30 cm) of either sandy loam topsoil or loam topsoil, should produce better stands of vegetation than carbonaceous shale alone. The addition of inorganic fertilizer is recommended as a soil amendment if carbonaceous shale is used as a surface material.

10. Neither soil salinity nor soil sodicity should be a significant barrier to plant growth on areas where at least 10 inches of topsoil are placed over carbonaceous shale overburden.

11. Excellent results in establishing desirable shrubs, trees, and even forbs, can be obtained on the Alton coal field by using container-grown nursery stock. Planting should be done before May 15. The provision of 1 or 2 qt (1 or 2 liters) of water to each plant at the time of planting is recommended.

12. On the basis of our 6-year study, the following species of forbs and woody plants are recommended for use on reclaimed areas of the Alton coal field:

Primary species:

Wood's rose
Antelope bitterbrush
Cliffrose
Fourwing saltbush
Skunkbush sumac
Black sagebrush
Mountain big sagebrush
Rubber rabbitbrush
Curlleaf cercocarpus
Alderleaf cercocarpus
Green ephedra
Squawapple
Golden currant
Corymbed eriogonum
Utah sweetvetch
Common globemallow
Beautiful penstemon
Palmer penstemon
Western yarrow

Secondary species:

Siberian peashrub
Russian-olive
Tatarian honeysuckle
Sand sagebrush
Apacheplume
Prostrate summercypress
Plumed whitesage

13. Fourwing saltbush ecotypes from southern Arizona and southern California have little chance to survive on the Alton coal field because they lack winter hardiness. Continued evaluations of ecotypes of this valuable forage species should be made on the Alton coal field.

14. Shrub survival and growth are better when shrubs are established in stands of perennial bunchgrass than when forced to compete with vigorous rhizomatous species. On areas where good shrub establishment is considered an important objective, consideration should be given to excluding rhizomatous grasses from the seed mixture.

15. Plants with aerial parts growing within 12 inches (30 cm) or so of the soil surface are exposed to a greater number of late spring and early autumn frosts than would be indicated by temperature data recorded at 54 inches (137 cm) above the surface. At the Alton 8-acre study site, frost-free periods from 1979 to 1982 ranged from 28 to 45 days shorter at 12 inches above ground than at 54 inches above ground.

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APPENDIX

Tables 41-69

Figures 41-62

Table 41.—Species of shrubs planted at seven sites within the Emery study area in 1978 and 1979

Scientific name	Source	Sites planted[1]
Artemisia nova	Kane Co., UT	1,2,3,4
Atriplex aptera	Yellowstone Co., MT	1,2,3,4,5
Atriplex bonnevillensis	Millard Co., UT	1,2,3,4,5
Atriplex canescens	Different sources[2]	1,2,3,4,5,6,7
A. canescens x *A. cuneata*	Wayne Co., UT	1,2,3,4,5
A. canescens x *A. idahoensis*[3]	Owyhee Co., ID	2,4,5,6
A. canescens x *A. obovata*	Sandoval Co., NM	6,7
A. canescens x *A. tridentata*	Tooele Co., UT	2,3,4,5,6,7
A. canescens x *A. confertifolia* x *A. canescens*	Churchill Co., NV	6,7
A. corrugata x *A. cuneata*	San Juan Co., NM	6,7
Atriplex falcata	Nevada	6,7
Atriplex gardneri[4]	Tooele Co., UT	1,2,3,4,5
Atriplex idahoensis[3]	Owyhee Co., ID	1,3,5
Atriplex lahontanensis[3]	Lander Co., NV	6,7
Atriplex navajoensis	Coconino Co., AZ	1,2,3,4
Atriplex obovata	San Juan Co., UT	1,2,3,4,5
Atriplex robusta[3]	Tooele Co., UT	1,2,3,4,5,6
Atriplex tooelensis[3]	Tooele Co., UT	1,2,3,4
Atriplex tridentata	Uintah Co., UT	1,2,3,4,5
A. tridentata x *A. bonnevillensis*	Juab Co., UT	6,7
Camphorosma monspeliaca	U.S.S.R.	1,2,3,4,5
Ceratoides lanata	Uintah and Kane Co., UT	1,2,3,4,5
Ceratoides papposa	U.S.S.R.	2,4,5
Ephedra nevadensis	Millard Co., UT	1,2,3,4
Eriogonum corymbosum	Emery Co., UT	1,2,4
Grayia spinosa	Uintah Co., UT and Kern Co., CA	1,2,3,4
Kochia prostrata	U.S.S.R.	1,2,3,4,5
Kochia prostrata villosissima	U.S.S.R.	1,2,3,4,5

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[1] Sites: 1 = Persayo soil, 2 = Penoyer soil, 3 = Castle Valley soil, 4 = shaley subsoil, 5 = Bluegate shale, 6 = Persayo soil *Atriplex* plots, 7 = Castle Valley soil *Atriplex* plots.

[2] ATCA sources: sites 1–5 = Kane Co., Utah; sites 6 and 7 = Yuma Co., Ariz., and Juab Co., Utah.

[3] Undescribed taxa, provided by Dr. Howard Stutz.

[4] Subsequently identified as *Atriplex tridentata*.

Table 42.—Mean air and soil temperatures (°C) for each month, May 16, 1979, through December 1982, Emery 6-acre study area

Date		Air at 54"	Soil temperature			
			Persayo series		Shaley subsoil	
			- 2"	- 8"	- 2"	- 8"
1979	May (16-31)	16.4	17.2	16.2	18.1	16.8
	June	19.8	20.8	19.3	21.5	19.8
	July	24.1	25.4	23.6	25.3	23.4
	August	21.0	22.2	21.8	22.7	22.0
	September	19.7	19.5	19.5	20.6	20.2
	October	11.7	12.0	13.5	13.4	14.8
	November	-.8	-.3	2.3	1.0	4.2
	December	-2.6	-4.5	-2.7	-3.0	-.5
1980	January	-2.2	-1.5	-.6	-1.3	.1
	February	.7	-.7	-.1	-.6	.3
	March	1.2	2.7	2.9	2.4	3.0
	April	7.9	7.8	7.4	9.0	8.2
	May	10.8	12.2	11.9	12.3	12.0
	June	20.5	19.7	18.3	20.5	18.9
	July	24.0	24.2	22.8	24.7	23.1
	August	21.4	22.7	22.2	23.0	22.4
	September	16.5	16.4	16.8	16.7	17.2
	October	9.5	8.6	9.9	9.4	11.2
	November	3.4	1.9	3.1	2.5	4.3
	December	2.0	-1.4	-.4	-.7	.9
	Annual mean	9.6	9.4	9.6	9.8	10.1
1981	January	1.0	-1.2	-.4	-.5	.9
	February	1.0	-.3	.1	.5	1.3
	March	2.8	3.4	3.5	3.2	3.8
	April	10.8	10.5	9.8	11.2	10.2
	May	12.1	14.5	13.8	14.5	13.9
	June	21.0	22.3	20.6	21.7	19.8
	July	23.3	24.4	23.2	24.1	22.8
	August	21.6	22.4	21.9	22.4	21.9
	September	17.7	17.5	17.8	17.9	18.3
	October	7.9	8.0	9.3	8.4	10.5
	November	3.6	—	2.6	2.8	4.9
	December	-1.3	—	-1.2	-2.0	0
	Annual mean	10.3		10.2	10.4	10.7
1982	January	-4.6	—	-2.0	-4.3	-2.5
	February	-2.8	—	-2.2	-2.8	-2.1
	March	2.9	—	3.3	3.2	3.4
	April	6.6	—	7.2	8.3	7.7
	May	12.5	—	13.2	14.8	13.5
	June	17.9	—	18.3	20.3	18.2
	July	22.2	—	22.6	24.3	22.2
	August	20.8	—	21.3	22.0	21.5
	September	15.1	—	16.7	16.6	17.5
	October	6.6	—	7.7	7.5	9.0
	November	-.1	—	1.0	.5	2.6
	December	-3.8	—	-2.2	-3.7	-1.5
	Annual mean	7.8	—	8.7	8.9	9.1

Table 43.—Mean maximum air and soil temperatures (°C) for each month, May 16, 1979, through December 1982, Emery 6-acre study area

			Soil temperature			
			Persayo series		Shaley subsoil	
Date		Air at 54″	− 2″	− 8″	− 2″	− 8″
1979	May (16 − 31)	24.6	23.8	18.1	23.8	18.3
	June	28.8	28.5	21.4	28.0	21.3
	July	33.3	33.6	25.3	32.0	24.6
	August	29.8	29.9	23.5	29.3	23.1
	September	29.3	27.3	21.0	27.6	21.3
	October	20.5	18.5	14.7	19.0	15.7
	November	5.9	3.3	3.1	4.5	5.0
	December	4.1	−2.0	−2.0	.1	0
1980	January	4.2	−.6	−.3	.1	.4
	February	8.6	.9	.4	1.1	.8
	March	7.8	5.0	3.7	5.5	3.9
	April	16.3	11.3	8.6	13.8	9.4
	May	18.3	16.3	13.3	17.5	13.4
	June	29.3	24.7	19.7	26.0	20.1
	July	32.9	29.9	24.3	31.3	24.3
	August	30.0	28.5	23.5	29.7	23.4
	September	24.9	21.3	17.4	21.2	18.4
	October	17.5	13.5	11.0	14.6	12.2
	November	11.4	4.4	2.8	5.9	5.1
	December	11.0	.2	.1	2.7	1.5
	Annual mean	17.6	13.0	10.5	14.1	11.1
1981	January	9.4	1.0	.2	3.1	1.6
	February	9.2	3.2	.9	5.1	2.0
	March	10.2	6.3	4.5	7.4	4.7
	April	19.0	14.8	11.2	16.8	11.6
	May	19.4	19.1	15.2	19.7	15.0
	June	29.9	28.5	22.2	28.7	21.1
	July	32.2	30.7	24.9	31.2	24.1
	August	31.7	29.2	23.5	30.0	23.2
	September	26.9	23.4	19.5	24.6	19.6
	October	15.4	12.7	10.5	13.7	11.5
	November	11.7	—	4.6	7.2	5.7
	December	6.6	—	−.6	.6	.5
	Annual mean	18.5	—	11.4	15.7	11.7
1982	January	4.1	—	−1.8	−2.4	−2.2
	February	6.4	—	−1.7	1.5	−1.5
	March	9.1	—	4.3	8.4	4.4
	April	14.4	—	8.6	15.0	9.1
	May	20.4	—	14.4	22.1	17.9
	June	26.8	—	19.8	29.0	19.5
	July	31.3	—	24.1	33.2	23.4
	August	30.5	—	22.9	30.1	22.7
	September	23.2	—	18.1	23.2	18.6
	October	15.0	—	9.0	13.1	10.1
	November	7.7	—	1.7	5.1	3.3
	December	4.2	—	−1.7	−2.9	−1.2
	Annual mean	16.1	—	9.8	14.6	10.3

Table 44.—Mean minimum air and soil temperatures (°C) for each month, May 16, 1979, through December 1982, Emery 6-acre study area

			Soil temperature			
			Persayo series		Shaley subsoil	
Date		Air at 54"	- 2"	- 8"	- 2"	- 8"
1979	May (16-31)	8.9	11.6	14.4	13.1	15.6
	June	10.9	14.0	17.4	15.6	18.6
	July	15.5	18.3	21.9	19.4	21.7
	August	13.5	16.0	20.2	17.1	21.0
	September	11.9	13.5	18.0	14.9	19.2
	October	5.5	7.3	12.3	8.9	14.1
	November	-5.9	-3.2	1.6	-1.8	3.5
	December	-7.5	-7.0	-3.3	-5.4	-1.0
1980	January	-6.7	-2.3	-.9	-2.5	-.2
	February	-4.4	-1.7	-.7	-1.8	0
	March	-4.0	1.1	2.3	.5	2.4
	April	.3	4.8	6.4	4.9	7.2
	May	4.6	8.4	10.7	8.1	10.9
	June	11.5	15.0	16.9	15.2	17.7
	July	15.4	19.0	21.5	19.0	21.3
	August	13.3	17.6	20.9	16.8	21.4
	September	9.2	12.4	14.9	11.9	16.2
	October	3.4	5.5	8.7	5.6	10.3
	November	-2.2	-.2	2.5	-.1	3.8
	December	-3.4	-3.0	-.2	-2.9	.5
	Annual mean	3.1	6.4	8.6	6.2	9.3
1981	January	-4.4	-2.9	-.8	-3.0	.4
	February	-5.2	-3.1	-.7	-3.0	.7
	March	-2.2	1.4	2.7	.5	3.0
	April	3.7	6.7	8.6	6.4	9.1
	May	5.2	10.5	12.7	10.1	13.0
	June	12.5	16.8	19.1	15.8	18.7
	July	15.4	18.8	21.7	18.2	21.7
	August	13.7	16.8	20.4	16.4	20.8
	September	10.8	12.9	16.2	12.6	17.1
	October	2.4	4.5	8.1	4.4	9.5
	November	-2.0	—	2.7	-.4	4.2
	December	-6.4	—	-1.6	-3.8	-.3
	Annual mean	3.6	—	9.1	6.2	9.8
1982	January	-10.0	—	-2.2	-6.1	-2.8
	February	-8.4	—	-2.6	-6.0	-2.6
	March	-2.0	—	2.4	-.7	2.6
	April	-.8	—	6.0	2.9	6.5
	May	5.3	—	11.9	8.9	12.4
	June	9.5	—	16.9	13.2	17.1
	July	14.0	—	21.2	17.1	21.1
	August	13.6	—	19.8	15.8	20.5
	September	8.9	—	15.6	11.7	16.6
	October	.4	—	6.4	3.2	8.0
	November	-5.4	—	.2	-2.9	1.9
	December	-8.1	—	-2.5	-4.4	-1.7
	Annual mean	1.4	—	7.6	4.4	8.3

Table 45.—Extreme maximum and minimum temperatures (°C) recorded at the Persayo-soil study site for each month, from May 1979 through Dercember 1982, Emery coal field

Month		1979			1980			1981			1982		
		Air at 54″	Soil		Air at 54″	Soil		Air at 54″	Soil		Air at 54″	Soil	
			2″	8″		2″	8″		2″	8″		2″	8″
Jan.—	Max.	—	—	—	11.9	4.8	2.0	16.1	4.2	1.5	13.5	—	-0.9
	Min.	—	—	—	-12.6	-8.1	-3.0	-9.4	-5.0	-2.0	-22.1	—	-2.8
Feb.—	Max.	—	—	—	15.4	6.0	3.5	15.1	7.0	3.7	20.1	—	4.0
	Min.	—	—	—	-12.4	-6.5	-3.6	-14.3	-6.6	-3.0	-21.2	—	-7.7
Mar.—	Max	—	—	—	13.1	7.8	4.8	17.4	10.1	6.9	17.1	—	6.5
	Min.	—	—	—	-11.7	.2	1.5	-6.6	-.8	1.2	-6.4	—	.9
Apr.—	Max.	—	—	—	26.1	17.4	13.3	28.3	21.5	16.7	24.9	—	12.9
	Min.	—	—	—	-10.7	0	1.2	-6.5	1.1	3.7	-7.6	—	3.2
May.—	Max.	29.3	28.1	19.9	29.6	21.1	16.6	28.8	24.4	18.5	28.9	—	17.7
	Min.	2.6	7.7	12.7	-1.4	5.4	8.3	-1.5	6.3	9.8	-.9	—	9.2
June—	Max.	37.1	34.1	24.4	34.5	29.2	23.0	38.8	34.5	25.7	34.1	—	23.8
	Min.	3.8	9.2	13.4	5.0	9.5	11.7	3.2	11.5	14.6	.8	—	13.1
July—	Max.	37.2	37.0	27.0	38.2	33.9	26.5	38.3	34.2	26.8	38.3	—	26.2
	Min.	9.3	14.7	19.4	10.6	14.3	18.3	12.4	16.3	19.5	4.5	—	17.6
Aug.—	Max.	38.1	36.2	27.3	36.7	34.2	26.7	38.7	34.8	26.7	36.7	—	25.5
	Min.	7.6	10.7	16.0	6.6	13.2	17.6	9.3	12.6	17.4	9.8	—	17.4
Sept.—	Max.	33.8	31.0	22.9	33.6	27.8	21.7	33.3	28.3	22.2	33.5	—	22.4
	Min.	6.4	9.6	15.7	2.6	8.7	12.7	6.1	9.3	13.6	1.7	—	9.3
Oct.—	Max.	29.4	23.8	19.1	30.4	20.2	16.6	26.7	21.6	17.4	21.1	—	11.6
	Min.	-7.3	-2.0	5.0	-5.1	-.4	2.8	-5.0	-.7	3.4	-5.2	—	3.3
Nov.—	Max.	12.1	9.0	6.8	21.1	10.2	7.9	20.6	[1]	7.1	17.0	—	6.2
	Min.	-13.9	-12.5	-5.7	-10.5	-5.1	-.9	-10.2	—	-.7	-10.8	—	-3.2
Dec.—	Max.	9.1	.8	.7	17.4	3.4	1.5	15.7	—	.8	9.5	—	.3
	Min.	-15.5	-13.9	-6.2	-8.7	-6.7	-2.7	-13.7	—	-4.1	-16.7	—	-6.7

[1] Temperature sensor ceased functioning in November 1981.

Table 46.—Mean temperature (°C) for each month, for the period 1955 to 1982 at Ferron, Utah

Month	Mean	Range	Month	Mean	Range
Jan.	-5.1	-9.6— 1.2	Jul.	22.4	21.3—24.2
Feb.	-1.8	-8.7— 2.8	Aug.	21.0	17.6—22.8
Mar.	2.6	-.1— 6.6	Sept.	16.3	13.0—19.1
Apr.	7.7	4.1—10.6	Oct.	10.1	5.9—12.6
May	13.2	9.8—16.2	Nov.	3.0	-.3— 5.3
June	18.8	15.3—23.6	Dec.	-3.1	-7.4— 1.6
Annual mean = 8.7, Range = 7.5—10.1					

Table 47.—Miscellaneous microclimatic data from the Emery study area

Item	1978[1]	1979	1980	1981	1982
Length of frost-free period (days)	134	168	142	158	147
No. days 0 °C or lower (5/1-10/15)	7	0	13	4	8
Extreme min. temp. (5/1-10/15)	-4.0	2.6	-5.1	-2.7	-3.4
No. days 32.2 °C, or higher	[2]38	43	45	42	28
No. days 32.2 °C or higher at Ferron	19	28	21	28	8
Dates between which the mean daily soil temp. of Persayo soil at 8 inches was 10 °C or higher	?	? 10/23	4/20 - 10/15	4/14 - 10/11	4/27 - 10/1
Max. rainfall in 1 hour (inches)	?	0.12	0.29	0.73	0.23
Max. rainfall in 24 hours (inches)	0.26	0.12	1.20	1.23	0.46
Max. rainfall in 7 days (inches)	0.57	0.13	2.19	2.64	1.00
No. consecutive days with no recorded rainfall ⩾ 0.25 inches (5/1-10/15)	87	184	60	58	103

[1] 1978 data from Ferron, Utah.

[2] Predicted from correlation between Ferron and Emery study area.

Table 48.—Cumulative growing degree days (°C) at the Emery study area for the years 1979 through 1982

Week beginning	1979	1980	1981	1982
Jan. 3	0	4	20	6
17	0	22	71	19
31	0	60	90	28
Feb. 14	6	88	133	60
Mar. 1	14	130	186	112
15	48	167	220	158
29	83	191	285	208
Apr. 12	172	270	415	277
26	279	386	562	375
May 10	373	484	658	477
24	550	610	796	629
June 7	730	794	1,002	787
21	933	1,006	1,197	984
July 5	1,162	1,230	1,410	1,185
19	1,396	1,469	1,645	1,428
Aug. 2	1,641	1,713	1,879	1,656
16	1,838	1,925	2,085	1,878
30	2,057	2,126	2,302	2,091
Sept. 13	2,264	2,299	2,490	2,243
27	2,469	2,470	2,676	2,374
Oct. 11	2,647	2,606	2,758	2,462
25	2,724	2,666	2,841	2,534
Nov. 8	2,759	2,752	2,923	2,576
22	2,774	2,786	2,966	2,598
Dec. 6	2,790	2,815	3,009	2,614
20	2,802	2,882	3,023	2,627
27	2,804	2,920	3,030	2,627

Table 49.—Long-term mean precipitation (inches) received at Emery, Utah, and precipitation received at the Emery study area during the period of study

Month	Long-term means for Emery, Utah	Precipitation during the study period					
		1977	1978	1979	1980	1981	1982
Jan.	0.47	[1]0.32	1.48	3.14	2.44	0.04	1.63
Feb.	.41	.20	1.67	.87	1.80	.04	.12
Mar.	.45	0	1.08	3.03	1.20	1.11	.49
Apr.	.42	.16	.33	.28	.50	.36	.03
May	.62	1.21	[2].57	[4].47	1.55	.33	.13
June	.69	.73	[3].06	.02	.10	1.13	.14
July	.71	1.17	.49	.01	.48	.33	.25
Aug.	1.17	1.13	.23	.07	.35	1.21	1.06
Sept.	.79	.45	.18	.13	2.23	2.82	1.32
Oct.	.85	.49	.30	.09	.62	1.27	0
Nov.	.40	.02	2.58	.27	.30	.26	.57
Dec.	.57	.40	.64	.19	.02	.18	.46
Annual mean	7.55	6.28	9.61	8.57	11.59	9.08	6.20

[1] Data from Emery, Utah, January 1977 through April 1978.

[2] Data from Ferron, Utah, May and December 1978, February 1979, December 1979 through March 1980, November and December 1980, and January 1982.

[3] Data from USGS gage in June through November 1978, and January and March 1979.

[4] Data from Emery study area, beginning May 1979, except as otherwise noted.

Table 50.—Precipitation received (inches) at the Emery study area, according to periods of the "water year," 1978 to 1982

October 1 to April 30		May 1 to September 30		Total
1977-78	5.47	1978	1.53	7.00
1978-79	7.81	1979	.70	8.51
1979-80	6.49	1980	4.71	11.20
1980-81	2.49	1981	5.82	8.31
1981-82	3.98	1982	2.90	6.88
Mean at Emery	3.57		3.98	7.55

Table 51.—Mean soil water potential as measured by thermocouple psychrometers at Emery study sites in 1980

Soil location	Soil depth	April 22	May 23	June 27	August 15	October 6
	Inches			*Bars*		
Persayo series Cultipacked	8	-7	-5	-9	-30	-2
	20	-6	-6	-9	-51	-8
Gouged	8	-8	-7	-6	-22	-7
	20	-8	-7	-2	-37	-12
Penoyer series Cultipacked	8	-10	-4	-36	-15	-5
	20	-8	-3	-23	-70	-7
Gouged	8	-7	-5	-10	-40	-5
	20	-6	-5	-2	-44	-5
Castle Valley series	8	-9	-3	-18	-13	-10
	20	-4	-5	-17	-70	-74
Bluegate shale Ripped	8	-10	-6	-9	-70	-6
	20	-13	-13	-12	-72	-35
Nonripped	8	-3	-2	-14	-48	-3
	20	-6	-6	-5	-9	-7
Shaley subsoil	8	-7	-6	-7	-16	-27
	20	-10	-12	-10	-12	-11

Table 52.—Mean soil water potential as measured by thermocouple psychrometers at Emery study sites in 1981

Soil location	Soil depth	Apr. 16	May 19	June 18	July 29	Aug. 19	Sept. 14	Oct. 20
	Inches	*Bars*						
Persayo series	8	−1	−6	−44	−70	*	−55	−28
Cultipacked	20	−7	−9	−37	−46	−61	−63	−50
Gouged	8	−1	−1	−28	−55	−52	−1	−1
	20	−4	−3	−20	−55	−66	−27	−1
Penoyer series	8	−1	−20	−76	−54	−79	−26	−7
Cultipacked	20	−1	−20	−60	−69	−75	−76	−48
Gouged	8	−1	−3	−32	−25	−45	−1	−2
	20	−2	−1	−24	−30	−43	−47	−20
Castle Valley	8	−4	−11	−76	−59	*	−11	−9
series	20	−34	−28	−69	−72	−79	−78	−70
Bluegate shale	8	−2	−9	−56	−65	*	−78	−18
Ripped	20	−29	−28	−54	−79	*	−52	−5
Nonripped	8	−1	−19	−45	−20	*	−3	−5
	20	−6	−4	−8	−15	−18	−20	−11
Shaley subsoil	8	−13	−12	−17	−11	−14	−9	−5
	20	−10	−11	−12	−10	−11	−9	−8

* = Soil too dry to obtain readings.

Table 53.—Species of container–grown shrubs planted on grass species plots on the 3–acre study site, Alton coal field

Common name	Scientific name	Source
Bonneville saltbush	*Atriplex bonnevillensis*	Millard Co., UT
Fourwing saltbush	*Atriplex canescens*	Sanpete Co., UT
Winterfat	*Ceratoides lanata*	Sanpete Co., UT
Curlleaf cercocarpus	*Cercocarpus ledifolius*	Utah Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Green ephedra	*Ephedra viridis*	Sanpete Co., UT
Prostrate summercypress	*Kochia prostrata*	U.S.S.R.
Villous prostrate summercypress	*Kochia prostrata villosissima*	U.S.S.R.
Antelope bitterbrush	*Purshia tridentata*	Nevada
Skunkbush sumac	*Rhus trilobata*	Judith Basin Co., MT

Table 54.—Plant species included in seed mixture sown in November 1976 on the Utah International cooperative study plots, Alton coal field

Common name	Scientific name	Source
'Fairway' crested wheatgrass	*Agropyron cristatum*	Wyoming
'Jose' tall wheatgrass	*Agropyron elongatum*	Colorado
'Rosana' western wheatgrass	*Agropyron smithii*	Montana
Russian wildrye	*Elymus junceus*	Colorado
Indian ricegrass	*Oryzopsis hymenoides*	Kansas
Alkali sacaton	*Sporobolus airoides*	Kansas
'Lutana' cicer milkvetch	*Astragalus cicer*	Wyoming
Arrowleaf balsamroot	*Balsamorhiza sagittata*	Sanpete Co., UT
Utah sweetvetch	*Hedysarum boreale*	Utah Co., UT
'Drylander' alfalfa	*Medicago media*	Saskatchewan
Small burnet	*Sanguisorba minor*	Oregon
Gooseberryleaf globemallow	*Sphaeralcea grossulariaefolia*	Millard Co., UT
Utah serviceberry	*Amelanchier oreophila*	Cassia Co., ID
Fourwing saltbush	*Atriplex canescens*	Kane Co., UT
Winterfat	*Ceratoides lanata*	Garfield Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Green ephedra	*Ephedra viridis*	Sanpete Co., UT
Antelope bitterbrush	*Purshia tridentata*	Sanpete Co., UT

Table 55.—Species of shrubs and forbs planted at the Alton 8-acre study site in 1977

Common name	Scientific name	Source
Utah serviceberry	*Amelanchier utahensis*	Cassia Co., ID
Indigobush	*Amorpha fruticosa*	Boise Co., ID
Black sagebrush	*Artemisia nova*	Alton, Kane Co., UT
Mountain big sagebrush	*Artemisia vaseyana*	Sanpete Co., UT
Fourwing saltbush	*Atriplex canescens*	Los Lunas, NM
Fremont barberry	*Berberis fremontii*	Garfield Co., UT
Siberian peashrub	*Caragana arborescens*	?
Wedgeleaf ceanothus	*Ceanothus cuneatus*	Jackson Co., OR
Winterfat	*Ceratoides lanata*	Kane Co., UT
Curlleaf cercocarpus	*Cercocarpus ledifolius*	Utah Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Sanpete Co., UT
Cliffrose	*Cowania stansburiana*	Salt Lake Co., UT
Piute cypress	*Cupressus nevadensis*	Kern Co., CA
Russian-olive	*Elaeagnus angustifolia*	Emery Co., UT
Green ephedra	*Ephedra viridis*	Sanpete Co., UT
Utah sweetvetch	*Hedysarum boreale*	Utah Co., UT
Prostrate summercypress	*Kochia prostrata*	U.S.S.R. (P.I. 330675)
Tatarian honeysuckle	*Lonicera tatarica*	?
Squawapple	*Peraphyllum ramossisimum*	Lincoln Co., NV
Shrubby cinquefoil	*Potentilla fruticosa*	Garfield Co., UT
Black chokecherry	*Prunus virginiana melanocarpa*	Utah Co., UT
Antelope bitterbrush	*Purshia tridentata*	?
Skunkbush sumac	*Rhus trilobata*	?
Golden currant	*Ribes aureum*	?
Wood's rose	*Rosa woodsii*	?
Blueberry elder	*Sambucus cerulea*	Sanpete Co., UT
Roundleaf buffaloberry	*Shepherdia rotundifolia*	Garfield Co., UT
Gooseberryleaf globemallow	*Sphaeralcea grossulariaefolia*	Sanpete Co., UT

Table 56.—Species of shrubs, forbs, and trees planted on the Alton "bulk sample" site, May 1980

Common name	Scientific name	Source
In randomized blocks:		
Western yarrow	*Achillea lanulosa*	Southern Idaho
Sand sagebrush	*Artemisia filifolia*	Garfield Co., UT
Lemmon's ceanothus	*Ceanothus lemmoni*	Shasta Co., CA
Birchleaf cercocarpus	*Cercocarpus betuloides*	Tehama Co., CA
Winterfat	*Ceratoides lanata*	Kane Co., UT
Plumed sage	*Ceratoides papposa*	U.S.S.R. (P.I. 371860)
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Rio Blanco Co., CO
Cliffrose	*Cowania stansburiana*	Utah
Corymbed eriogonum	*Eriogonum corymbosum*	Kane Co., UT
Apache-plume	*Fallugia paradoxa*	?
Galleta	*Hilaria jamesii*	SCS, Los Lunas, NM
Utah sweetvetch	*Hedysarum boreale*	Salt Lake Co., UT
Creeping juniper	*Juniperus horizontalis*	Rosebud Co., MT
Beautiful penstemon	*Penstemon venustus*	Idaho
Desert bitterbrush	*Purshia glandulosa*	Nye Co., NV
Yucca	*Yucca* spp.	Washington Co., UT
Skunkbush sumac	*Rhus trilobata*	Washington Co., UT
Wood's rose	*Rosa woodsii*	Rosebud Co., MT
Wood's rose	*Rosa woodsii*	Kane Co., UT
Common globemallow	*Sphaeralcea coccinea*	Kane Co., UT
Nelson globemallow	*Sphaeralcea parvifolia*	Kane Co., UT
Needle-and-thread	*Stipa comata*	Salt Lake Co., UT
In windbreak plot:		
Utah serviceberry	*Amelanchier utahensis*	Washington Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Piute cypress	*Cupressus nevadensis*	Kern Co., CA
Velvet ash	*Fraxinus velutina*	Washington Co., UT
Hybrid poplar	*Populus* spp.[1]	Europe
Western black chokecherry	*Prunus virginiana*	Utah Co., UT
Gambel oak	*Quercus gambelii*	Garfield Co., UT

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[1] Five of each of the following were planted: No. 302 (*P.* cv. 'Betufolia' x *P. trichocarpa*), No. NE-4 (*P. nigra* x *P. laurifolia*), No. 253 (*P.* cv. 'Angulata' x *P. trichocarpa*), and No. 353 (*P. deltoides* x *P.* cv. 'Caudina').

Table 57.—Seed source of 20 accessions of fourwing saltbush planted in May 1980 on the Alton bulk sample site

Holbrook, Navajo Co., AZ
Tuba City, Coconino Co., AZ
Tucson, Pima Co., AZ
Yuma, Yuma Co., AZ
Yuma (35 mi E.), Yuma Co., AZ
Joshua Forest, Riverside Co., CA
Delta, Delta Co., CO
Guaymas, Mexico
Tularosa, Otero Co., NM
Bernalillo, Sandoval Co., NM
Adrian, Malheur Co., OR
Nyssa, Malheur Co., OR
Ephraim (Excel Canyon), Sanpete Co., UT
Sanpete Co., UT
Huntington, Emery Co., UT
Jericho Sand Dunes, Juab Co., UT
Jericho Sand Dunes (gigas), Juab Co., UT
Johnson Canyon, Kane Co., UT
Myton, Duchesne Co., UT
Douglas, Converse Co., WY

Table 58.—Physical and chemical properties of topsoil and subsoil by soil amendment treatment 6 years after treatment, Alton 8–acre study site

Properties	Topsoil-hay	Topsoil-compost	Topsoil-control	Subsoil-hay	Subsoil-compost	Subsoil-control
Sand (percent)	30	43	37	31	40	37
Silt (percent)	37	30	35	35	34	35
Clay (percent)	33	27	28	34	26	28
Saturation (percent)	52	55	50	46	46	46
CEC (meq/100 g)	20	22	26	15	19	14
NH_4OAc extractable						
Na (meq/100 g)	0.27	0.22	0.20	0.21	0.20	0.20
Ca (meq/100 g)	52	53	50	49	52	48
Water soluble cations						
Na (meq/100 g)	0.02	0.02	0.02	0.02	0.02	0.03
Ca (meq/100 g)	0.18	0.25	0.18	0.13	0.22	0.13
P; $NaHCO_3$ (ppm)	1.1	1.4	1.3	0.5	2.1	0.5
N; NO_3 (ppm)	0.8	1.2	0.9	0.9	1.1	1.4
ECe (mmhos/cm)	0.4	0.5	0.4	0.4	0.5	0.4
Na adsorption ratio	0.3	0.2	0.3	0.3	0.3	0.5
pH	7.8	7.9	7.8	7.8	8.0	8.0

Table 59.—Physical and chemical properties of carbonaceous shale overburden (clay loam) and three types of topsoil from the Alton coal field

Properties	Clay loam	Sandy loam topsoil	Loam topsoil	Silty clay topsoil
Bulk density	1.34	1.35	1.50	1.01
Sand (percent)	32	63	41	6
Silt (percent)	31	23	34	40
Clay (percent)	37	14	25	54
Saturation (percent)	56	26	36	59
Percent moisture at				
0.1 atm	31.3	19.8	25.7	36.4
0.33 atm	23.9	10.0	18.2	29.1
15 atm	15.3	4.3	9.0	15.9
Color (moist)	10 yr, 4/1	5 yr, 3/3	10 yr, 3/2	5 yr, 5/1
CEC (meq/100 g)	32.6	9.2	17.1	40.2
NH_4OAc extractable				
Na (meq/100 g)	0.5	0.2	0.3	1.3
Water soluble cations				
Na (meq/100 g)	0.2	≤0.1	≤0.1	0.2
Ca (meq/100 g)	1.4	0.1	0.2	0.1
Mg (meq/100 g)	1.7	≤0.1	0.1	≤0.1
K (meq/100 g)	≤0.1	≤0.1	0.1	≤0.1
Exch. Na (meq/100 g)	0.3	0.2	0.2	1.0
Exch. Na (percent)	1.0	2.0	1.0	3.0
Na adsorption ratio	0.5	0.8	0.6	3.1
$NaHCO_3$ – P (ppm)	31.0	16.0	12.0	0.6
NO_3 – N (ppm)	1.4	3.8	27.0	1.6
ECe (mmhos/cm)	3.3	0.6	1.1	0.6
pH	7.6	7.6	7.7	8.5

Table 60.—Physical and chemical properties of four soil materials on the Alton 3-acre study site

Properties	Sandy loam topsoil	Silty clay subsoil	Clay loam subsoil	Carbonaceous shale overburden
Sand (percent)	57	3	14	26
Silt (percent)	26	42	42	39
Clay (percent)	17	55	44	35
Saturation (percent)	44	71	81	46
CEC (meq/100 g)	19	29	48	17
NH_4OAc extractable				
Na (meq/100 g)	0.22	0.22	0.53	0.19
Ca (meq/100 g)	49	50	39	42
Water soluble cations				
Na (meq/100 g)	0.02	0.03	0.07	0.02
Ca (meq/100 g)	0.25	0.09	0.08	0.09
P; $NaHCO_3$ (ppm)	5.2	0.5	0.5	0.5
N; NO_3 (ppm)	4.0	1.0	0.8	0.4
ECe (mmhos/cm)	0.6	0.3	0.4	0.3
Na adsorption ratio	0.2	0.3	0.7	0.2
pH	7.9	8.3	8.3	8.0

Table 61.—Mean daily air and soil temperatures (°C) for each month from May 1979 through December 1982 at the town of Alton and the Alton 8-acre study area

		Study area			
Date	Alton	Air at 54"	Air at 12"	Soil at -2"	Soil at -8"
1979 May (18-31)	13.6	14.1	13.6		14.5
June	15.5	18.4	17.6		19.0
July	19.1	22.2	21.4		22.9
August	17.2	19.4	19.0		21.8
September	16.7	18.9	18.1		20.6
October	10.5	12.5	11.5		16.1
November	.6	1.2	.4		6.0
December	.6	.5	-.8		2.7
1980 January	-1.0	0	-.8		1.9
February	.3	2.5	-.1		1.7
March	-.7	1.5	0		1.4
April	5.8	7.9	7.7		7.6
May	9.0	10.0	9.7		11.2
June	15.1	18.4	17.2		18.5
July	19.1	21.2	20.5		21.6
August	17.2	20.1	19.7		22.2
September	14.5	17.1	16.6		18.9
October	9.1	10.0	9.2		13.0
November	4.0	4.9	3.9		6.3
December	3.4	4.2	3.3		3.9
1981 January	1.2	2.1	1.5		3.6
February	1.0	2.5	2.0		3.8
March	1.9	2.7	2.7		5.1
April	8.5	9.5	9.2		10.0
May	10.5	12.0	11.9		14.3
June	17.5	20.8	20.7		20.8
July	20.1	22.7	22.8	24.6	23.2
August	18.1	20.2	20.1	20.8	21.4
September	14.7	16.6	16.3	13.7	18.2
October	7.1	8.0	7.8	1.0	11.0
November	4.2	5.4	4.7	-4.0	6.7
December	1.1	1.9	1.3	-.3	3.0
1982 January	-3.5	-1.8	-3.3	.3	1.4
February	-1.0	.9	-.6	1.9	—
March	1.4	2.3	2.1	4.6	—
April	5.4	7.0	6.9	9.7	—
May	10.6	12.2	12.0	15.8	—
June	14.4	17.3	17.1	21.5	18.7
July	17.9	21.1	21.2	25.3	22.6
August	17.9	19.6	19.9	21.6	21.3
September	13.7	15.1	15.2	16.6	17.6
October	6.7	7.8	7.7	8.4	11.1
November	.9	1.9	1.6	2.2	5.2
December	-3.1	-.8	-1.9	-.6	2.9

Table 62.—Mean daily maximum air and soil temperatures (°C) for each month from May 1979 through December 1982 at the town of Alton and the Alton study area

			Study area			
	Date	**Alton**	**Air at 54″**	**Air at 12″**	**Soil at −2″**	**Soil at −8″**
1979	May (18–31)	22.7	22.8	24.4		15.6
	June	26.1	26.8	29.4		20.4
	July	29.4	31.6	35.4		24.3
	August	26.6	28.6	31.5		23.2
	September	26.7	28.5	32.3		21.8
	October	20.1	21.4	28.5		17.1
	November	8.3	8.8	11.4		6.6
	December	9.2	9.1	11.4		3.2
1980	January	4.6	6.6	4.5		1.9
	February	7.3	10.8	3.7		1.7
	March	6.4	8.8	5.4		1.7
	April	14.2	15.2	17.3		8.5
	May	17.2	16.9	18.8		11.8
	June	26.4	26.9	29.2		19.8
	July	28.6	30.4	33.9		22.9
	August	26.7	28.8	32.9		23.5
	September	23.6	25.7	29.5		19.1
	October	17.9	18.8	22.1		13.9
	November	12.8	14.0	18.0		7.0
	December	11.3	13.5	17.3		4.4
1981	January	9.8	10.8	14.7		4.2
	February	10.0	11.2	14.9		4.3
	March	8.9	9.6	12.7		5.7
	April	17.6	17.2	20.7		10.8
	May	19.2	19.5	23.2		15.3
	June	27.7	29.3	33.5		22.0
	July	29.4	31.4	35.8	36.6	24.3
	August	27.3	29.4	33.2	31.5	22.4
	September	23.7	25.2	28.7	24.6	19.1
	October	14.2	15.4	18.3	8.8	11.8
	November	12.0	13.1	15.8	2.4	7.3
	December	8.4	9.4	11.9	2.3	3.4
1982	January	3.8	6.0	5.3	.6	1.4
	February	6.8	9.3	8.9	4.1	—
	March	7.3	8.5	10.8	9.5	—
	April	14.1	14.4	17.6	16.6	—
	May	20.1	19.6	23.3	24.6	—
	June	25.0	25.8	30.7	33.2	20.1
	July	27.7	29.7	34.4	37.3	24.1
	August	25.8	28.5	32.9	31.1	22.9
	September	21.2	23.0	27.0	24.9	18.9
	October	15.4	15.8	19.9	16.2	12.2
	November	7.3	8.2	10.9	5.1	5.7
	December	3.5	6.9	7.2	−.1	3.0

Table 63.—Mean daily minimum air and soil temperatures (ºC) for each month from May 1979 through December 1982 at the town of Alton and the Alton study area

		Study area			
Date	Alton	Air at 54″	Air at 12″	Soil at −2″	Soil at −8″
1979 May (18–31)	4.4	6.5	4.7		13.5
June	4.9	9.0	6.1		17.6
July	8.8	12.4	8.9		21.5
August	7.7	11.0	7.9		20.6
September	6.6	10.2	6.2		19.5
October	.9	4.5	.2		15.1
November	−7.1	−4.8	−8.8		5.5
December	−8.1	−5.6	−9.6		2.2
1980 January	−6.6	−4.3	−4.7		1.6
February	−6.8	−3.6	−2.7		1.7
March	−7.9	−4.7	−5.1		1.2
April	−2.6	1.0	−1.0		6.8
May	.8	2.3	.8		10.4
June	3.7	8.5	4.8		17.2
July	9.6	12.2	9.6		20.4
August	7.7	11.5	7.8		21.0
September	5.3	8.8	5.2		17.8
October	.3	2.4	−1.1		11.6
November	−4.8	−2.3	−6.6		5.7
December	−4.5	−2.3	−5.6		3.6
1981 January	−7.4	−4.4	−8.8		3.2
February	−8.0	−4.8	−8.1		3.4
March	−5.1	−3.0	−5.5		4.6
April	−.6	1.7	−1.1		9.2
May	1.7	4.4	1.7		13.5
June	7.2	11.4	7.8		19.7
July	10.7	14.4	11.3	15.3	22.2
August	8.9	12.3	9.8	12.6	20.4
September	5.7	9.5	6.8	5.9	17.3
October	0	1.9	−.4	−4.3	10.4
November	−3.6	−1.0	−3.8	−8.2	6.2
December	−6.2	−4.3	−6.8	−2.0	2.8
1982 January	−10.8	−8.5	−10.8	.2	1.3
February	−8.9	−5.6	−8.3	.5	—
March	−4.5	−2.7	−4.7	1.8	—
April	−3.2	−.7	−3.2	4.2	—
May	1.2	4.3	1.2	8.6	—
June	3.8	7.5	4.1	12.2	17.3
July	8.1	12.2	8.9	15.8	21.0
August	10.0	13.0	11.3	15.1	19.7
September	6.2	8.7	6.8	10.8	16.4
October	−2.1	.7	−2.0	2.8	9.9
November	−5.5	−3.3	−5.3	.6	4.7
December	−9.7	−6.5	−8.6	−1.1	2.8

Table 64.—Extreme temperatures (°C) for each month from May 1979 through December 1982, Alton 8-acre study area

		Air				Soil			
		At 54"		At 12"		At 2"		At 8"	
Date		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1979	May	27.2	1.5	28.9	.1			16.3	12.5
	June	34.0	.2	36.7	0			23.7	14.1
	July	35.3	7.5	39.7	4.5			26.1	19.6
	August	36.0	5.4	40.2	3.7			26.6	16.1
	September	33.1	4.8	37.5	.7			23.6	17.1
	October	29.1	-7.8	33.2	-12.3			20.2	8.9
	November	13.7	-12.0	16.6	-16.3			9.8	1.5
	December	17.4	-14.5	20.0	-20.6			5.2	.7
1980	January	15.7	-10.7	10.2	-11.3			2.5	.6
	February	18.6	-12.8	9.8	-10.6			2.1	1.1
	March	18.6	-11.0	12.2	-14.7			4.3	.8
	April	25.3	-5.9	27.3	-7.0			11.4	2.0
	May	26.4	-3.4	27.8	-5.2			14.6	7.8
	June	32.3	2.3	35.7	.1			23.3	12.6
	July	35.9	8.2	40.2	5.3			25.0	17.7
	August	35.2	5.9	39.6	2.3			25.8	17.8
	September	31.1	.7	36.2	-3.1			22.4	16.1
	October	31.8	-4.9	35.9	-9.3			20.2	6.2
	November	22.1	-11.7	25.7	-17.4			10.5	2.4
	December	23.0	-10.9	27.0	-12.5			5.8	2.2
1981	January	18.5	-17.4	23.1	-21.4			5.5	2.0
	February	20.0	-11.3	24.5	-14.0			6.8	1.8
	March	17.0	-8.8	20.8	-11.3			8.4	2.6
	April	24.1	-7.6	27.5	-11.1			14.3	5.6
	May	29.1	-2.9	32.9	-6.0			17.2	11.0
	June	35.9	.1	39.8	-2.8			25.3	14.7
	July	38.3	11.3	41.1	7.8	42.2	12.0	25.7	19.9
	August	37.9	6.4	42.0	5.5	42.8	7.8	26.7	17.5
	September	29.2	4.9	33.7	2.3	31.7	-.7	22.2	15.6
	October	24.6	-5.2	29.3	-9.2	20.4	-9.7	17.8	6.4
	November	21.9	-11.0	25.2	-13.5	8.0	-13.4	9.2	3.1
	December	18.1	-12.3	20.0	-14.9	8.9	-10.0	5.3	1.3
1982	January	17.1	-22.8	17.2	-27.4	3.7	-.2	1.8	1.1
	February	17.1	-20.7	18.8	-23.9	14.2	-.1	—	—
	March	15.0	-10.8	18.6	-12.9	14.9	-.3	—	—
	April	24.0	-10.2	27.0	-15.0	23.8	1.4	—	—
	May	25.2	-3.8	30.4	-5.7	32.0	3.9	—	—
	June	32.3	1.0	37.9	-2.0	40.1	8.0	23.4	15.4
	July	35.7	4.6	40.8	0	42.3	10.8	25.8	17.9
	August	32.6	9.4	37.8	7.0	36.2	10.7	25.4	17.8
	September	32.6	0	38.8	-1.7	32.8	4.4	24.2	11.6
	October	21.8	-6.7	26.6	-9.1	20.0	-.6	13.8	6.5
	November	17.7	-10.8	21.7	-13.8	11.0	-.8	9.1	3.2
	December	17.5	-15.5	16.7	-17.3	1.7	-6.9	4.0	1.0

Table 65.—Long-term means (1941 to 1970) of monthly temperature (°C) and precipitation (inches) for the town of Alton, Kane County, Utah

Month	Mean temperature	Mean precipitation
January	-2.7	1.90
February	-1.3	1.49
March	.7	1.48
April	5.7	1.25
May	10.3	.78
June	14.7	.64
July	19.0	1.43
August	18.1	1.94
September	14.4	1.23
October	9.0	1.19
November	2.7	1.26
December	-1.4	1.79
Annual mean	7.4	16.38

Table 66.—Miscellaneous microclimatic data from the Alton study area

Item	1979	1980	1981	1982
Length of frost-free period at 54″	156	141	147	141
Length of frost-free period at 12″	118	113	115	96
Length of frost-free period at Alton (NOAA)	124	108	114	91
No. days 0 °C, or lower, at 54″ (5/1-10/31)	6	19	17	16
No. days 0 °C, or lower, at 12″ (5/1-10/31)	11	34	32	34
Extreme min. temp. at 54″ (5/1-10/31), °C	-7.8	-4.9	-5.2	-6.7
Extreme min. temp. at 12″ (5/1-10/31), °C	-12.3	-9.3	-9.2	-9.1
No. days ≥32 °C at 54″	31	23	27	14
No. days ≥32 °C at 12″	74	56	76	62
Extreme max. temp. at 54″, °C	36.0	35.9	38.3	35.7
Extreme max. temp. at 12″, °C	40.0	40.2	42.0	40.8
Dates between which mean daily soil temp. at 8 inches = 10 °C or higher	? 10/31	4/19 10/22	4/10 10/22	— 10/27
Max. rainfall in 1 hour (inch)	0.21	0.46	0.22	0.73
Max. rainfall in 24 hours (inch)	0.66	0.66	0.69	0.82
Max. rainfall in 7 days (inch)	1.20	1.14	1.40	1.48
Max. consecutive days with no recorded rainfall ≥0.25 inches (5/1-10/31)	79	46	45	91
Max. consecutive days no recorded rain	18	17	28	26

Table 67.—Cumulative "growing degree days" at the Alton 8-acre study site, 1979 to 1982

Week beginning		1979	1980	1981	1982
Jan.	3	2	6	31	7
	17	7	27	98	31
	31	7	76	120	63
Feb.	14	32	104	179	107
Mar.	1	51	152	220	161
	15	84	209	263	193
	29	108	231	319	230
Apr.	12	176	317	424	306
	26	276	420	552	400
May	10	378	505	660	487
	24	512	616	784	639
June	7	681	772	979	787
	21	858	959	1,180	974
July	5	1,063	1,155	1,410	1,169
	19	1,284	1,369	1,634	1,388
Aug.	2	1,507	1,595	1,860	1,600
	16	1,683	1,811	2,051	1,822
	30	1,882	2,000	2,262	2,032
Sept.	13	2,083	2,189	2,437	2,184
	27	2,273	2,368	2,603	2,324
Oct.	11	2,438	2,498	2,680	2,415
	25	2,523	2,574	2,771	2,496
Nov.	8	2,567	2,674	2,862	2,540
	22	2,597	2,723	2,916	2,568
Dec.	6	2,650	2,769	2,969	2,602
	20	2,690	2,854	3,005	2,627
	27	2,701	2,899	3,009	2,629

Table 68.—Precipitation (inches) received at the town of Alton from October 1976 through September 1982, and at the 8-acre study site from May 1979 through September 1982

		Alton	Study area		Alton	Study area
1976				Oct.	.72	—
				Nov.	.15	—
				Dec.	.05	—
1977	Jan.	1.00	—	July	2.38	—
	Feb.	.03	—	Aug.	1.64	—
	Mar.	.20	—	Sept.	.96	—
	Apr.	.05	—	Oct.	1.02	—
	May	2.34	—	Nov.	.16	—
	June	.40	—	Dec.	1.35	—
				TOTAL	11.53	
1978	Jan.	2.65	—	July	.33	—
	Feb.	2.19	—	Aug.	.70	—
	Mar.	4.38	—	Sept.	1.39	—
	Apr.	2.04	—	Oct.	.83	—
	May	.60	—	Nov.	5.72	—
	June	0	—	Dec.	3.25	—
				TOTAL	24.08	
1979	Jan.	3.25	—	July	.34	.46
	Feb.	2.45	—	Aug.	1.55	1.46
	Mar.	3.78	—	Sept.	.11	.29
	Apr.	.02	—	Oct.	.41	.55
	May	1.02	[1].82	Nov.	.71	.97
	June	0	.11	Dec.	.53	.55
				TOTAL	14.17	—
1980	Jan.	6.38	4.56	July	2.41	1.32
	Feb.	4.48	7.47	Aug.	1.69	.75
	Mar.	1.86	2.28	Sept.	2.85	1.44
	Apr.	.88	.60	Oct.	1.31	.91
	May	1.72	1.32	Nov.	.11	.10
	June	.01	.27	Dec.	.23	.46
				TOTAL	23.93	21.48
1981	Jan.	.40	.12	July	.78	.66
	Feb.	.37	.72	Aug.	2.43	2.11
	Mar.	2.47	3.27	Sept.	1.22	1.53
	Apr.	1.13	1.08	Oct.	2.85	1.39
	May	.91	1.72	Nov.	1.48	.28
	June	.35	.12	Dec.	.06	.49
				TOTAL	14.45	13.49
1982	Jan.	2.46	1.62	July	1.27	.32
	Feb.	.85	.57	Aug.	2.71	1.35
	Mar.	2.44	3.55	Sept.	2.65	2.82
	Apr.	.71	.61	Oct.	1.09	.78
	May	.53	.68	Nov.	4.30	2.83
	June	.12	.22	Dec.	1.96	2.08
				TOTAL	21.09	17.43

[1] Data for May 19–31 only.

Table 69.—List of plant symbols used in figures and tables

Symbol	Scientific name	Common name
ACLA	*Achillea lanulosa*	Western yarrow
AGCR	*Agropyron cristatum*	Fairway crested wheatgrass
AGCR(H)	*A. cristatum*	Crested wheatgrass hybrid
AGCR(R)	*A. cristatum*	Rhizomatous crested wheatgrass
AGDE	*A. desertorum*	Standard crested wheatgrass
AGEL	*A. elongatum*	Tall wheatgrass
AGIN	*A. inerme*	Beardless bluebunch wheatgrass
AGIN[2]	*A. intermedium*	Intermediate wheatgrass
AGRI	*A. riparium*	Streambank wheatgrass
AGSM	*A. smithii*	Western wheatgrass
AGSP x AGRE	*A. spicatum* x *A. repens* hybrid	
AGTR[2]	*A. tricophorum*	Pubescent wheatgrass
AMFR	*Amorpha fruticosa*	Indigobush
AMUT	*Amelanchier utahensis*	Utah serviceberry
ARFI	*Artemisia filifolia*	Sand sagebrush
ARNO	*A. nova*	Black sagebrush
ARTR	*A. tridentata vaseyana*	Mountain big sagebrush
ASGL	*Astragalus globiceps*	Milkvetch
ATAP	*Atriplex aptera*	Shortwing saltbush
ATBO	*A. bonnevillensis*	Bonneville saltbush
ATCA	*A. canescens*	Fourwing saltbush
ATCA x ATCU	*A. canescens* x *A. cuneata* hybrid	
ATCA x ATID	*A. canescens* x *A. idahoensis*[1] hybrid	
ATCA x ATOB	*A. canescens* x *A. obovata* hybrid	
ATCA x ATTR	*A. canescens* x *A. tridentata* hybrid	
ATCA x ATCO x ATCA	*A. canescens* x *A. confertifolia* x *A. canescens* hybrid	
ATCOR x ATCU	*A. corrugata* x *A. cuneata* hybrid	
ATFA	*A. falcata*	Falcate saltbush
ATGA	*A. gardneri*	Gardner saltbush
ATID	*A. idahoensis*[1]	Idaho saltbush
ATLA	*A. lahontanensis*[1]	Lahontan saltbush
ATNA	*A. navajoensis*	Navajo saltbush
ATOB	*A. obovata*	Broadscale saltbush
ATRO	*A. robusta*[1]	
ATTO	*A. tooelensis*[1]	
ATTR	*A. tridentata*	Trident saltbush
ATTR x ATBO	*A. tridentata* x *A. bonnevillensis* hybrid	
BEFR	*Berberis fremontii*	Fremont barberry
BOGR	*Bouteloua gracilis*	Blue grama
BRIN	*Bromus inermis*	Smooth brome
CAAR	*Caragana arborescens*	Siberian peashrub
CAMO	*Camphorosma monspeliaca*	Mediterranean camphorfume
CECU	*Ceanothus cuneatus*	Wedgeleaf ceanothus
CELE[2]	*C. lemmoni*	Lemmon's ceanothus
CELA	*Ceratoides lanata*	Winterfat
CEPA	*C. papposa*	Plumed whitesage
CEBE	*Cercocarpus betuloides*	Birchleaf cercocarpus
CELE	*C. ledifolius*	Curlleaf cercocarpus
CEMO	*C. montanus*	Alderleaf cercocarpus
CHNA	*Chrysothamnus nauseosus*	Rubber rabbitbrush
COST	*Cowania stansburiana*	Cliffrose
CUNE	*Cupressus nevadensis*	Piute cypress
ELAN	*Elaeagnus angustifolia*	Russian-olive
ELCI	*Elymus cinereus*	Great Basin wildrye
ELJU	*E. junceus*	Russian wildrye
EPNE	*Ephedra nevadensis*	Nevada ephedra
EPVI	*E. viridis*	Green ephedra
ERCO	*Eriogonum corymbosum*	Corymbed eriogonum
FAPA	*Fallugia paradoxa*	Apacheplume
FRVE	*Fraxinus velutina*	Velvet ash

[1] Undescribed taxa provided by Dr. Howard Stutz.

(con.)

Table 69.—(con.)

Symbol	Scientific name	Common name
GRSP	*Grayia spinosa*	Spiny hopsage
HEBO	*Hedysarum boreale*	Utah sweetvetch
HIJA	*Hilaria jamesii*	Galleta
JUHO	*Juniperus horizontalis*	Creeping juniper
KOPR	*Kochia prostrata*	Prostrate summercypress
KOVI	*K. prostrata villosissima*	Villous prostrate summercypress
LOTA	*Lonicera tatarica*	Tatarian honeysuckle
MEME	*Medicago media*	'Drylander' alfalfa
ORHY	*Oryzopsis hymenoides*	Indian ricegrass
PEPA	*Penstemon palmeri*	Palmer penstemon
PEVE	*P. venustus*	Beautiful penstemon
PERA	*Peraphyllum ramosissimum*	Squawapple
POFR	*Potentilla fruticosa*	Shrubby cinquefoil
POPLAR	*Populus* spp.	Hybrid poplar
PRVI	*Prunus virginiana*	Western black chokecherry
PUGL	*Purshia glandulosa*	Desert bitterbrush
PUTR	*P. tridentata*	Antelope bitterbrush
QUGA	*Quercus gambelii*	Gambel oak
RHTR	*Rhus trilobata*	Skunkbush
RIAU	*Ribes aureum*	Golden currant
ROWO	*Rosa woodsii*	Wood's rose
SACE	*Sambucus cerulea*	Blueberry elder
SHRO	*Shepherdia rotundifolia*	Roundleaf buffaloberry
SIHY	*Sitanion hystrix*	Squirreltail
SPCO	*Sphaeralcea coccinea*	Common globemallow
SPGR	*S. grossulariaefolia*	Gooseberryleaf globemallow
SPPA	*S. parvifolia*	Nelson globemallow
SPAI	*Sporobolus airoides*	Alkali sacaton
SPCR	*S. cryptandrus*	Sand dropseed
STCO	*Stipa comata*	Needle-and-thread
YUCCA	*Yucca* spp.	Yucca

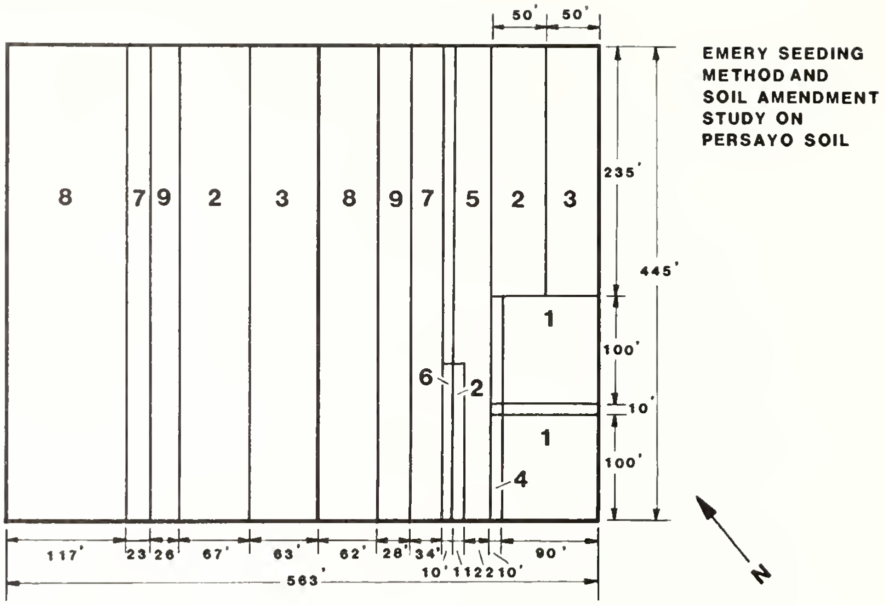


Figure 41.—Field plot design for the study of alternative site preparation methods and organic soil amandments on the Persayo soil series, Emery, Utah.

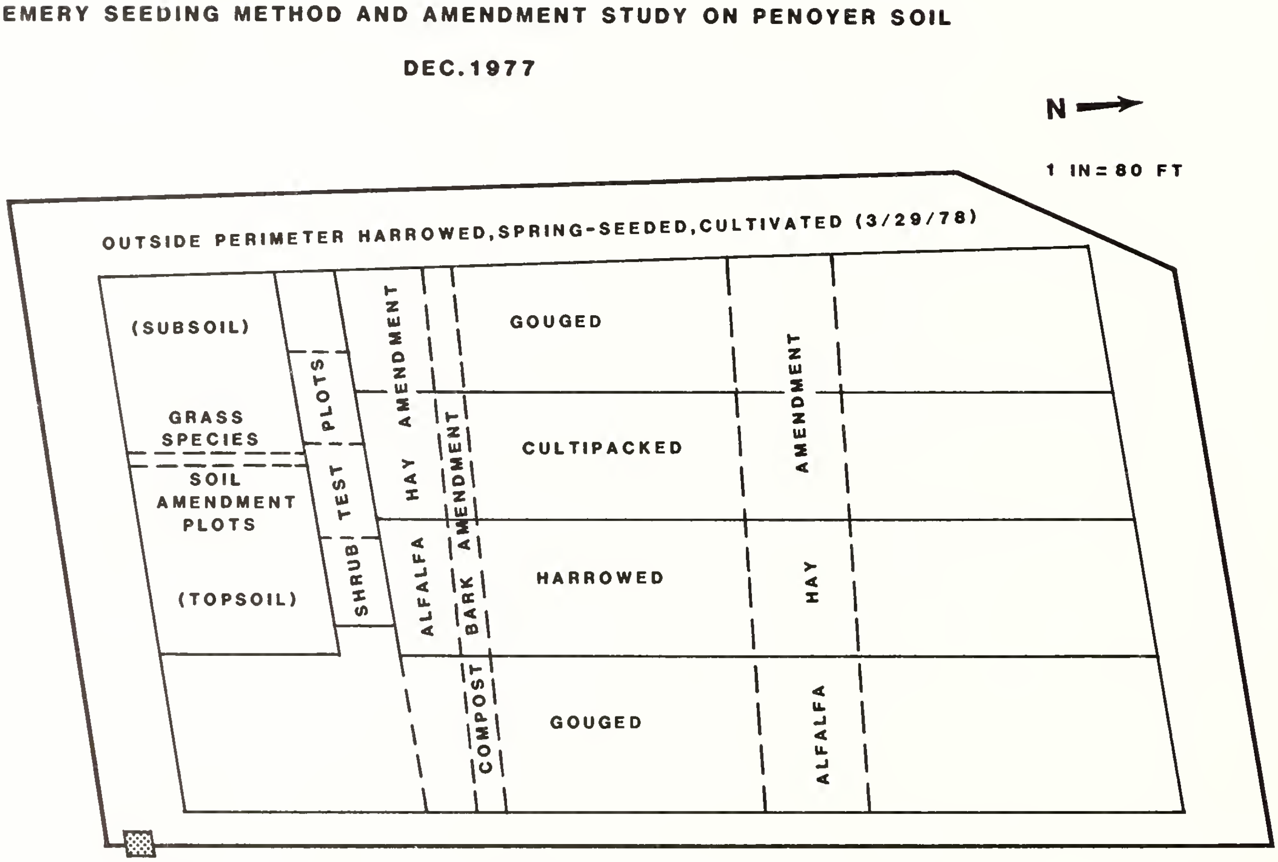
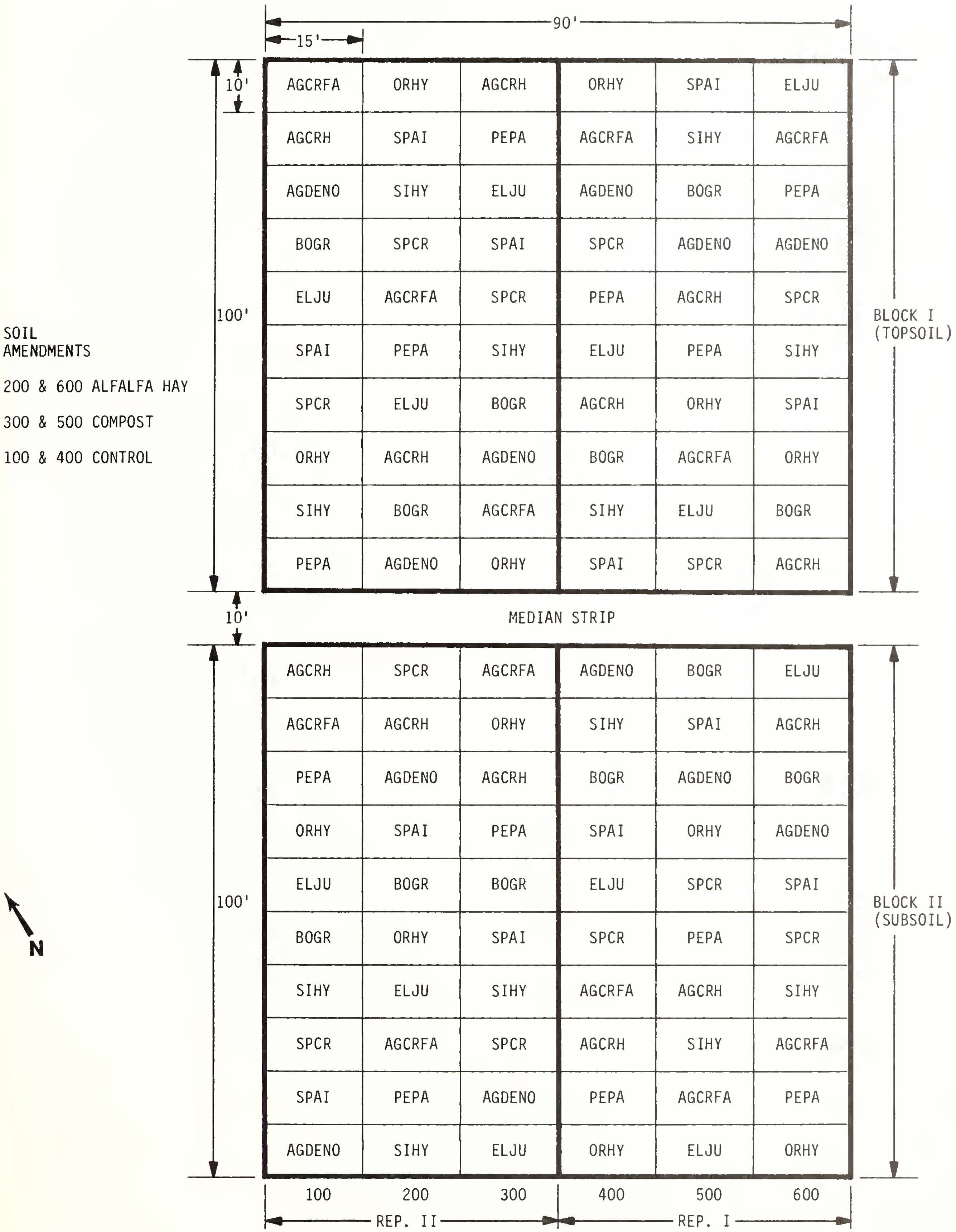


Figure 42.—Field plot design for the study of alternative site preparation methods and organic soil amendments on the Penoyer soil series, Emery, Utah.



SOIL AMENDMENTS

200 & 600 ALFALFA HAY

300 & 500 COMPOST

100 & 400 CONTROL

BLOCK I (TOPSOIL)

100	200	300	400	500	600
AGCRFA	ORHY	AGCRH	ORHY	SPAI	ELJU
AGCRH	SPAI	PEPA	AGCRFA	SIHY	AGCRFA
AGDENO	SIHY	ELJU	AGDENO	BOGR	PEPA
BOGR	SPCR	SPAI	SPCR	AGDENO	AGDENO
ELJU	AGCRFA	SPCR	PEPA	AGCRH	SPCR
SPAI	PEPA	SIHY	ELJU	PEPA	SIHY
SPCR	ELJU	BOGR	AGCRH	ORHY	SPAI
ORHY	AGCRH	AGDENO	BOGR	AGCRFA	ORHY
SIHY	BOGR	AGCRFA	SIHY	ELJU	BOGR
PEPA	AGDENO	ORHY	SPAI	SPCR	AGCRH

BLOCK II (SUBSOIL)

100	200	300	400	500	600
AGCRH	SPCR	AGCRFA	AGDENO	BOGR	ELJU
AGCRFA	AGCRH	ORHY	SIHY	SPAI	AGCRH
PEPA	AGDENO	AGCRH	BOGR	AGDENO	BOGR
ORHY	SPAI	PEPA	SPAI	ORHY	AGDENO
ELJU	BOGR	BOGR	ELJU	SPCR	SPAI
BOGR	ORHY	SPAI	SPCR	PEPA	SPCR
SIHY	ELJU	SIHY	AGCRFA	AGCRH	SIHY
SPCR	AGCRFA	SPCR	AGCRH	SIHY	AGCRFA
SPAI	PEPA	AGDENO	PEPA	AGCRFA	PEPA
AGDENO	SIHY	ELJU	ORHY	ELJU	ORHY

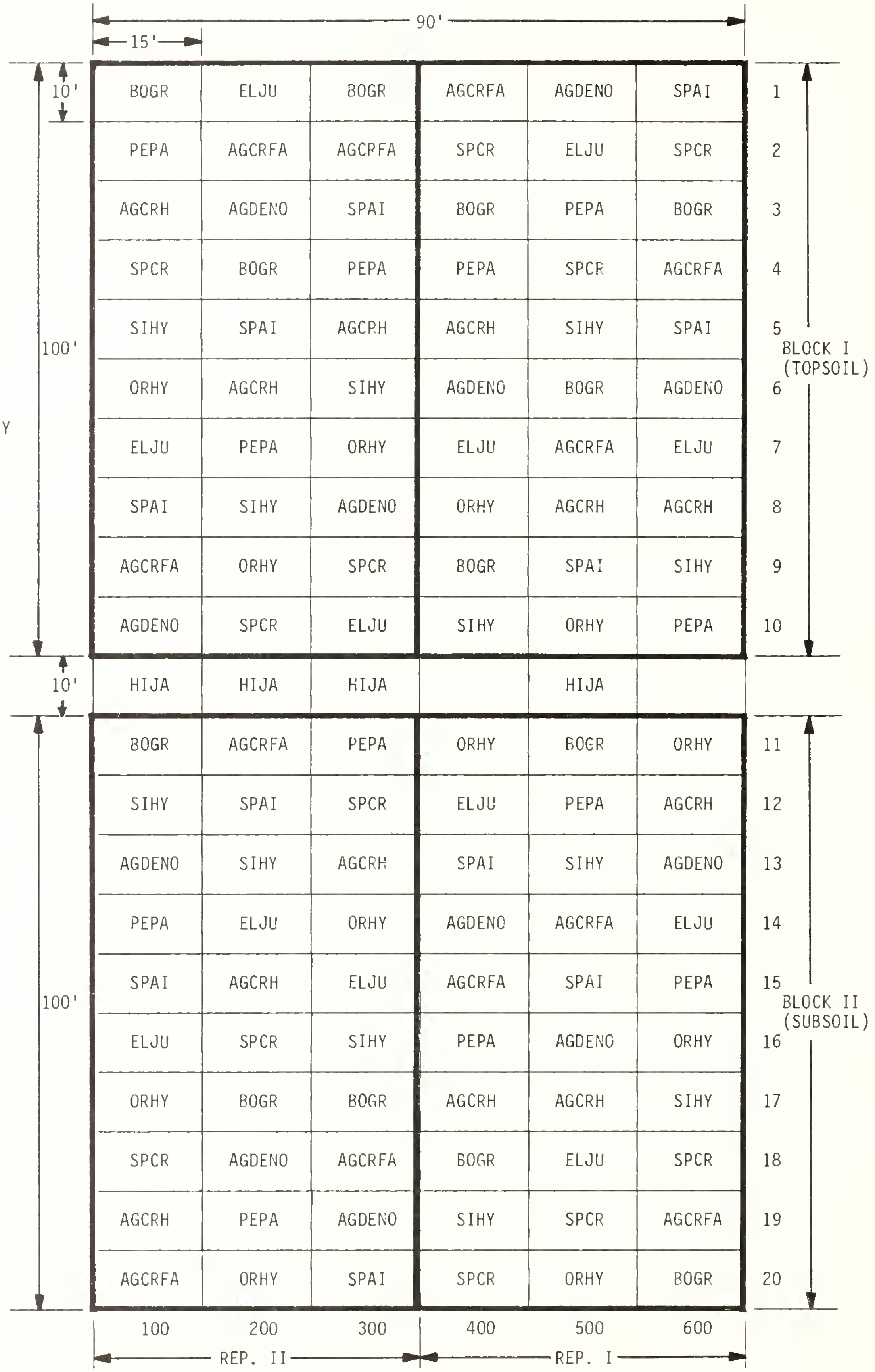
Figure 43.—Field plot design for the evaluation of organic soil amendments and different herbaceous species on the Persayo soil series, Emery, Utah.

SOIL
AMENDMENTS

100 & 500 ALFALFA HAY

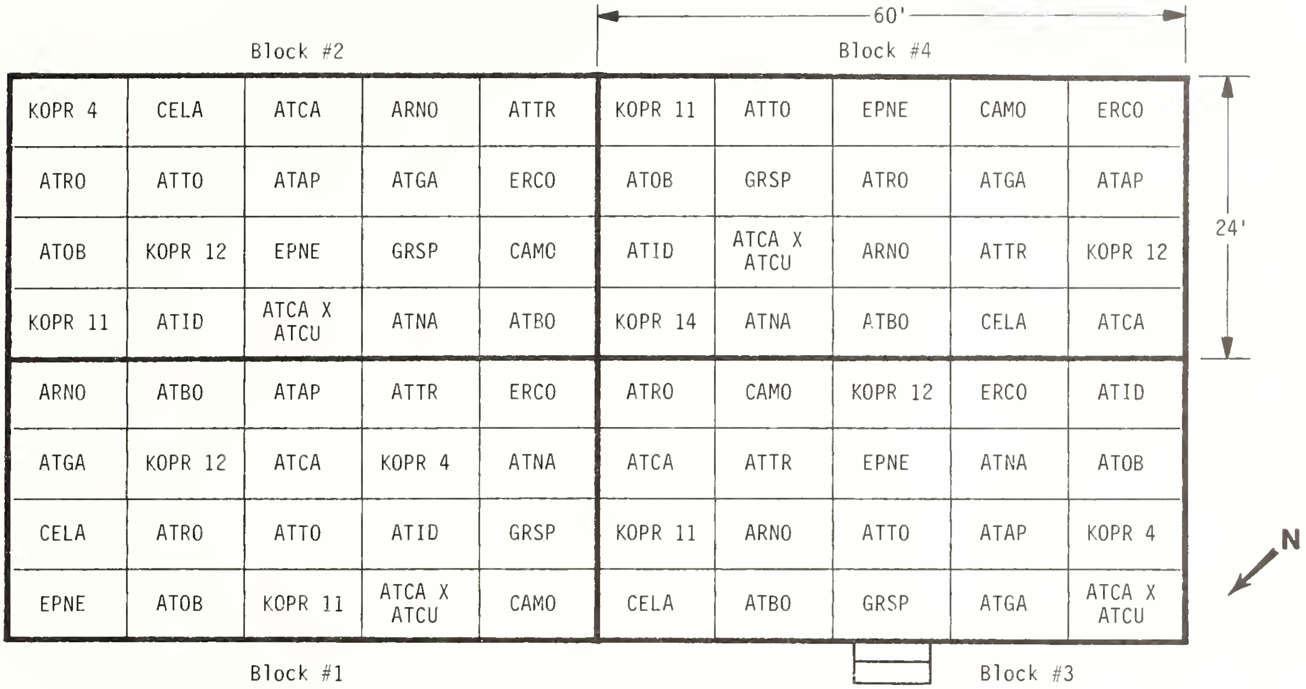
200 & 400 COMPOST

300 & 600 CONTROL



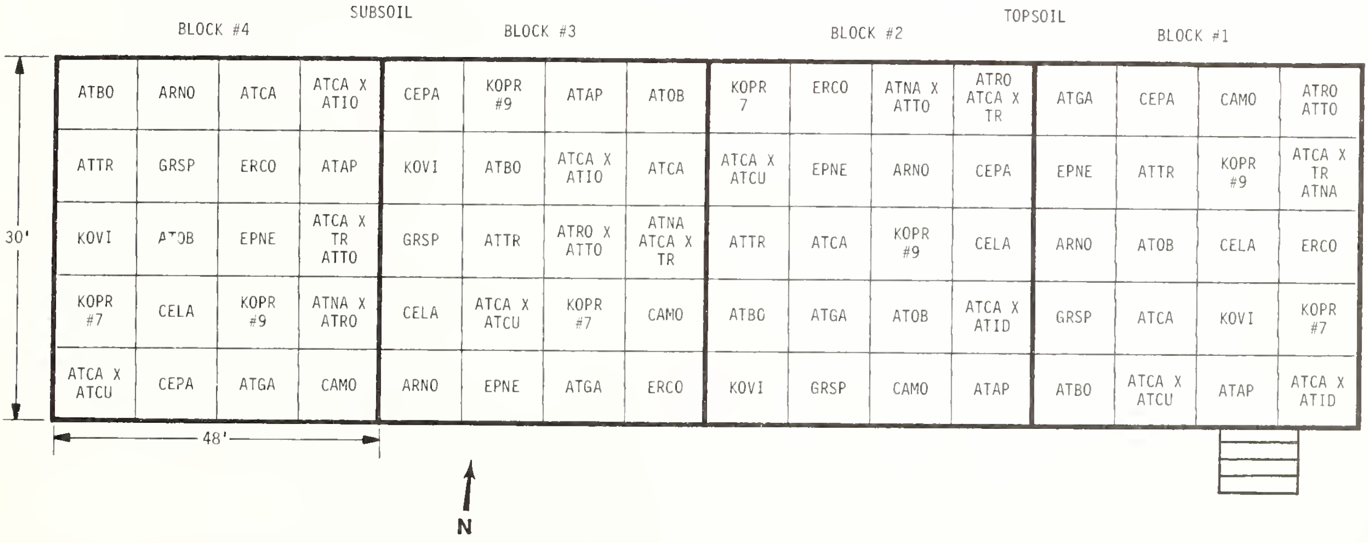
	100	200	300	400	500	600
1	BOGR	ELJU	BOGR	AGCRFA	AGDENO	SPAI
2	PEPA	AGCRFA	AGCRFA	SPCR	ELJU	SPCR
3	AGCRH	AGDENO	SPAI	BOGR	PEPA	BOGR
4	SPCR	BOGR	PEPA	PEPA	SPCR	AGCRFA
5	SIHY	SPAI	AGCRH	AGCRH	SIHY	SPAI
6	ORHY	AGCRH	SIHY	AGDENO	BOGR	AGDENO
7	ELJU	PEPA	ORHY	ELJU	AGCRFA	ELJU
8	SPAI	SIHY	AGDENO	ORHY	AGCRH	AGCRH
9	AGCRFA	ORHY	SPCR	BOGR	SPAI	SIHY
10	AGDENO	SPCR	ELJU	SIHY	ORHY	PEPA
	HIJA	HIJA	HIJA		HIJA	
11	BOGR	AGCRFA	PEPA	ORHY	BOGR	ORHY
12	SIHY	SPAI	SPCR	ELJU	PEPA	AGCRH
13	AGDENO	SIHY	AGCRH	SPAI	SIHY	AGDENO
14	PEPA	ELJU	ORHY	AGDENO	AGCRFA	ELJU
15	SPAI	AGCRH	ELJU	AGCRFA	SPAI	PEPA
16	ELJU	SPCR	SIHY	PEPA	AGDENO	ORHY
17	ORHY	BOGR	BOGR	AGCRH	AGCRH	SIHY
18	SPCR	AGDENO	AGCRFA	BOGR	ELJU	SPCR
19	AGCRH	PEPA	AGDENO	SIHY	SPCR	AGCRFA
20	AGCRFA	ORHY	SPAI	SPCR	ORHY	BOGR

Figure 44.—Field plot design for the evaluation of organic soil amendments and different herbaceous species on the Penoyer soil series, Emery, Utah.



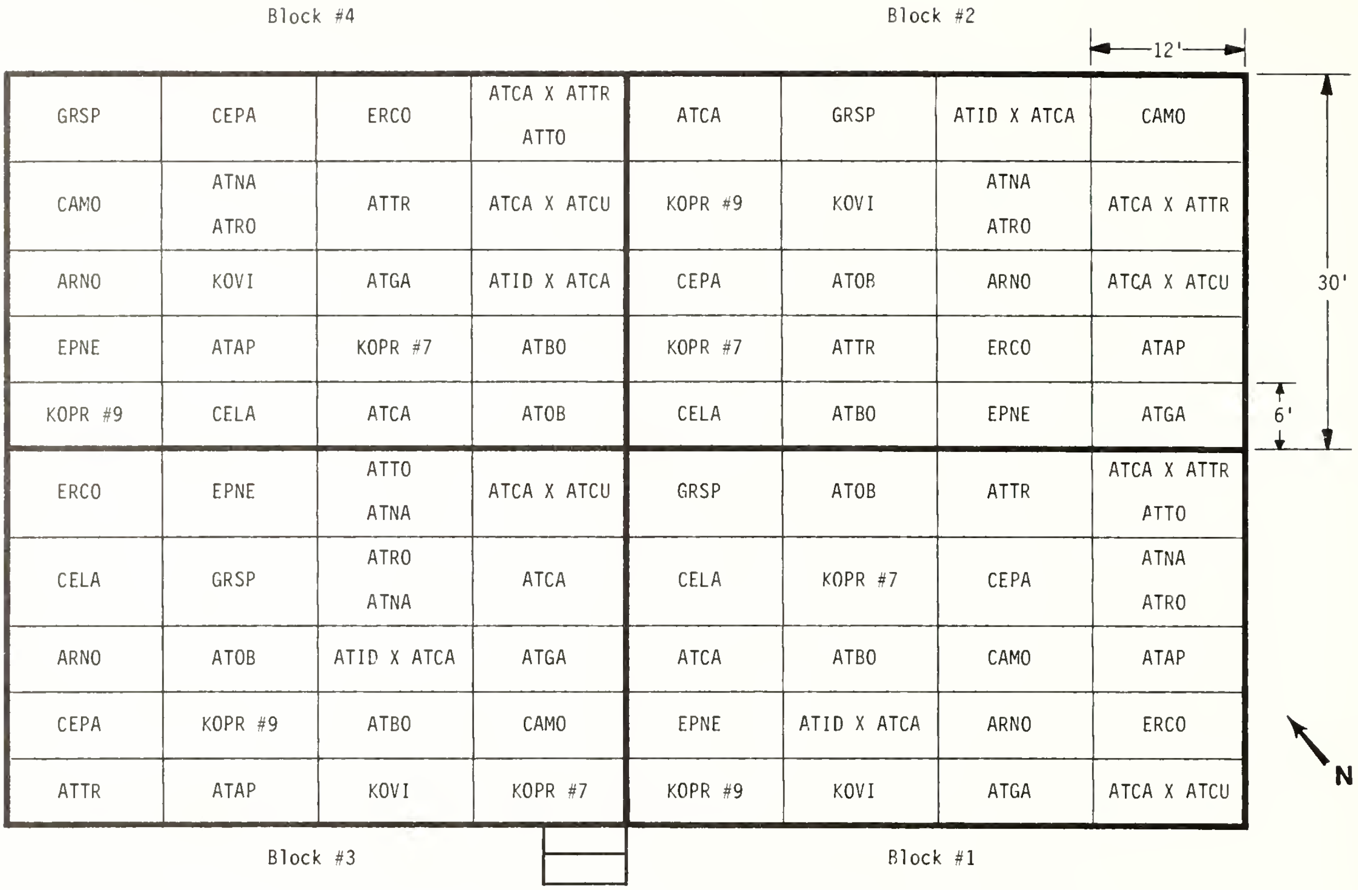
KOPR 4	CELA	ATCA	ARNO	ATTR	KOPR 11	ATTO	EPNE	CAMO	ERCO
ATRO	ATTO	ATAP	ATGA	ERCO	ATOB	GRSP	ATRO	ATGA	ATAP
ATOB	KOPR 12	EPNE	GRSP	CAMO	ATID	ATCA X ATCU	ARNO	ATTR	KOPR 12
KOPR 11	ATID	ATCA X ATCU	ATNA	ATBO	KOPR 14	ATNA	ATBO	CELA	ATCA
ARNO	ATBO	ATAP	ATTR	ERCO	ATRO	CAMO	KOPR 12	ERCO	ATID
ATGA	KOPR 12	ATCA	KOPR 4	ATNA	ATCA	ATTR	EPNE	ATNA	ATOB
CELA	ATRO	ATTO	ATID	GRSP	KOPR 11	ARNO	ATTO	ATAP	KOPR 4
EPNE	ATOB	KOPR 11	ATCA X ATCU	CAMO	CELA	ATBO	GRSP	ATGA	ATCA X ATCU

Figure 45.—Field plot design for testing shrub adaptability on Persayo soil, Emery coal field. See appendix table 69 for plant symbol key.



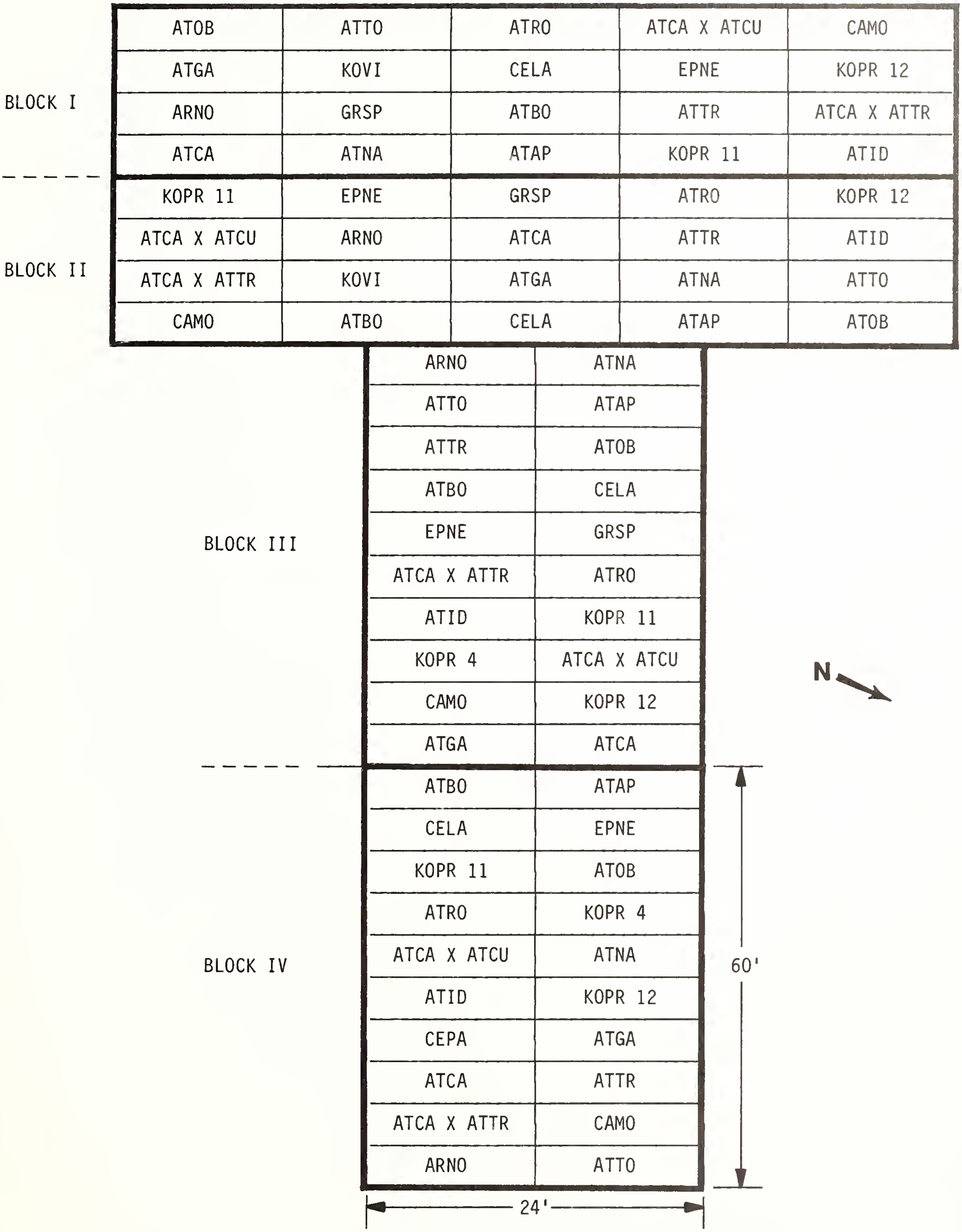
ATBO	ARNO	ATCA	ATCA X ATIO	CEPA	KOPR #9	ATAP	ATOB	KOPR 7	ERCO	ATNA X ATTO	ATRO ATCA X TR	ATGA	CEPA	CAMO	ATRO ATTO
ATTR	GRSP	ERCO	ATAP	KOVI	ATBO	ATCA X ATIO	ATCA	ATCA X ATCU	EPNE	ARNO	CEPA	EPNE	ATTR	KOPR #9	ATCA X TR ATNA
KOVI	ATOB	EPNE	ATCA X TR ATTO	GRSP	ATTR	ATRO X ATTO	ATNA ATCA X TR	ATTR	ATCA	KOPR #9	CELA	ARNO	ATOB	CELA	ERCO
KOPR #7	CELA	KOPR #9	ATNA X ATRO	CELA	ATCA X ATCU	KOPR #7	CAMO	ATBO	ATGA	ATOB	ATCA X ATID	GRSP	ATCA	KOVI	KOPR #7
ATCA X ATCU	CEPA	ATGA	CAMO	ARNO	EPNE	ATGA	ERCO	KOVI	GRSP	CAMO	ATAP	ATBO	ATCA X ATCU	ATAP	ATCA X ATID

Figure 46.—Field plot design for testing shrub adaptability on Penoyer soil, Emery coal field. See appendix table 69 for plant symbol key.



GRSP	CEPA	ERCO	ATCA X ATTR ATTO	ATCA	GRSP	ATID X ATCA	CAMO
CAMO	ATNA ATRO	ATTR	ATCA X ATCU	KOPR #9	KOVI	ATNA ATRO	ATCA X ATTR
ARNO	KOVI	ATGA	ATID X ATCA	CEPA	ATOB	ARNO	ATCA X ATCU
EPNE	ATAP	KOPR #7	ATBO	KOPR #7	ATTR	ERCO	ATAP
KOPR #9	CELA	ATCA	ATOB	CELA	ATBO	EPNE	ATGA
ERCO	EPNE	ATTO ATNA	ATCA X ATCU	GRSP	ATOB	ATTR	ATCA X ATTR ATTO
CELA	GRSP	ATRO ATNA	ATCA	CELA	KOPR #7	CEPA	ATNA ATRO
ARNO	ATOB	ATID X ATCA	ATGA	ATCA	ATBO	CAMO	ATAP
CEPA	KOPR #9	ATBO	CAMO	EPNE	ATID X ATCA	ARNO	ERCO
ATTR	ATAP	KOVI	KOPR #7	KOPR #9	KOVI	ATGA	ATCA X ATCU

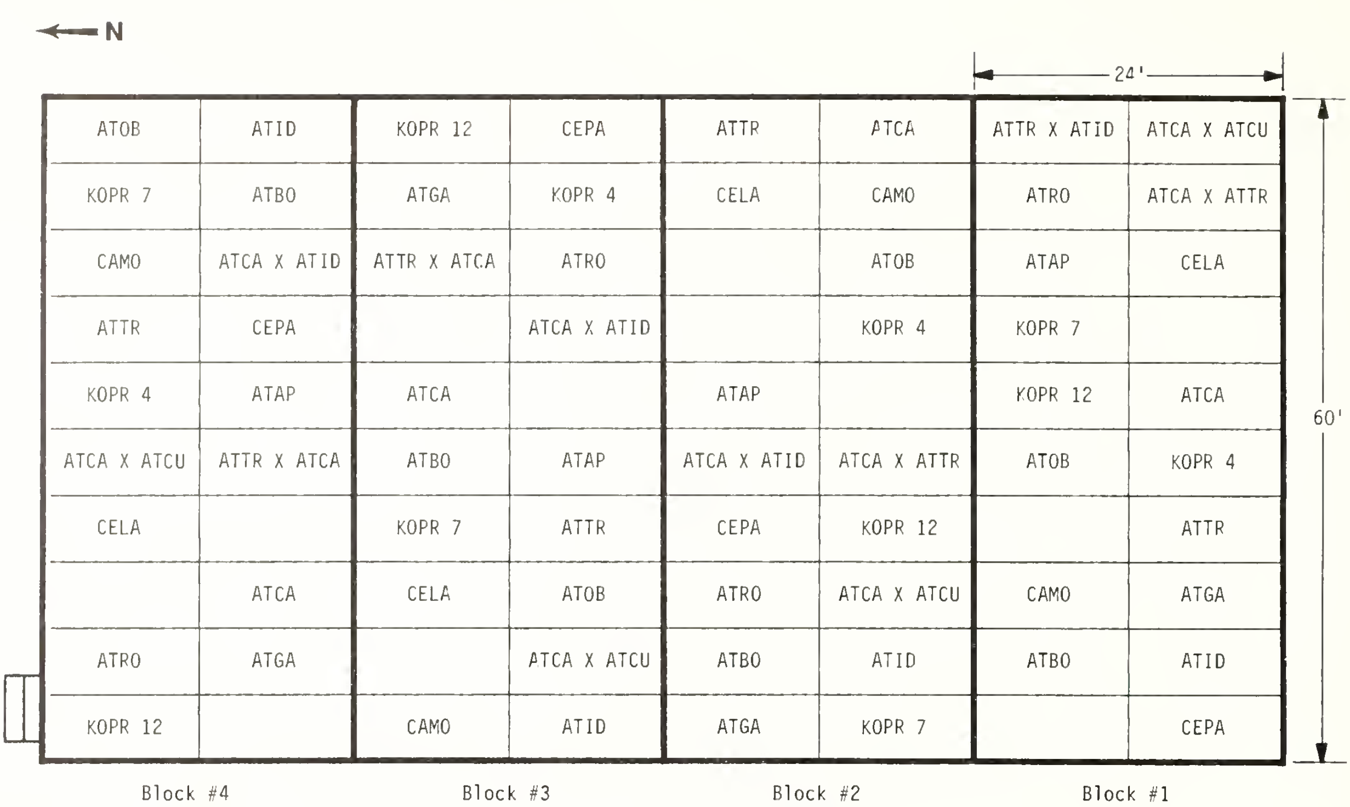
Figure 47.—Field plot design for testing shrub adaptability on shaley subsoil, Emery coal field. See appendix table 69 for plant symbol key.



BLOCK I	ATOB	ATTO	ATRO	ATCA X ATCU	CAMO
	ATGA	KOVI	CELA	EPNE	KOPR 12
	ARNO	GRSP	ATBO	ATTR	ATCA X ATTR
	ATCA	ATNA	ATAP	KOPR 11	ATID
BLOCK II	KOPR 11	EPNE	GRSP	ATRO	KOPR 12
	ATCA X ATCU	ARNO	ATCA	ATTR	ATID
	ATCA X ATTR	KOVI	ATGA	ATNA	ATTO
	CAMO	ATBO	CELA	ATAP	ATOB

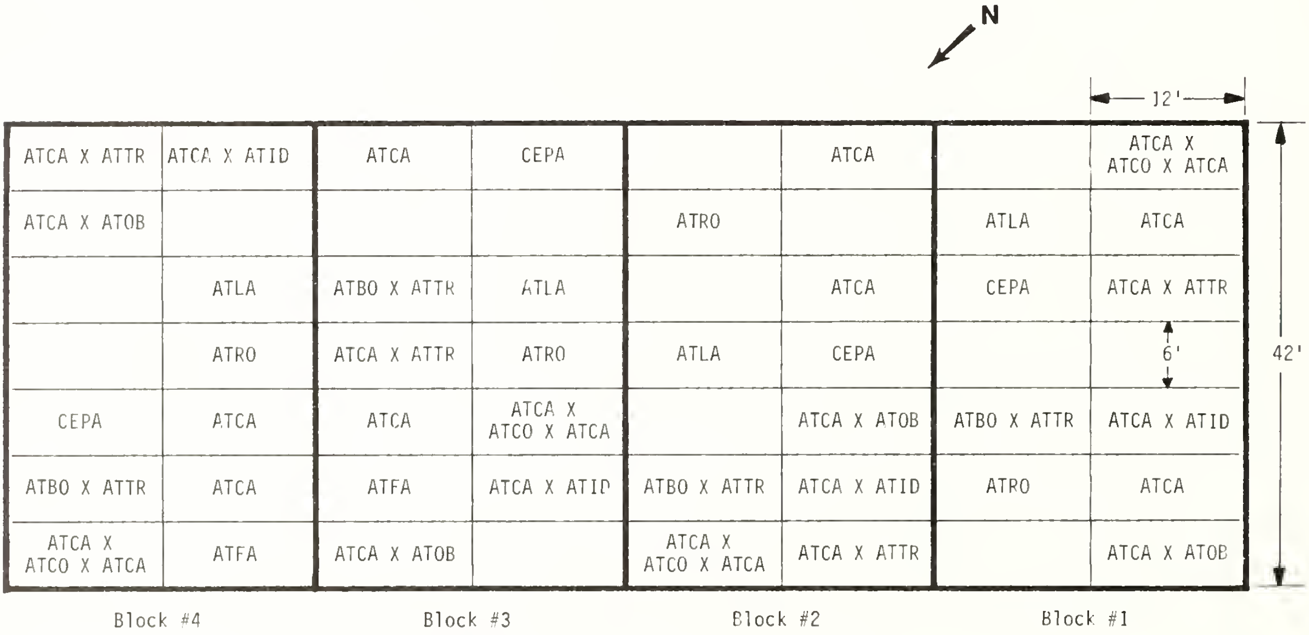
BLOCK III	ARNO	ATNA
	ATTO	ATAP
	ATTR	ATOB
	ATBO	CELA
	EPNE	GRSP
	ATCA X ATTR	ATRO
	ATID	KOPR 11
	KOPR 4	ATCA X ATCU
	CAMO	KOPR 12
	ATGA	ATCA
BLOCK IV	ATBO	ATAP
	CELA	EPNE
	KOPR 11	ATOB
	ATRO	KOPR 4
	ATCA X ATCU	ATNA
	ATID	KOPR 12
	CEPA	ATGA
	ATCA	ATTR
	ATCA X ATTR	CAMO
	ARNO	ATTO

Figure 48.—Field plot design for testing shrub adaptability on Castle Valley soil series, Emery coal field. See appendix table 69 for plant symbol key.



Block #4		Block #3		Block #2		Block #1	
ATOB	ATID	KOPR 12	CEPA	ATTR	ATCA	ATTR X ATID	ATCA X ATCU
KOPR 7	ATBO	ATGA	KOPR 4	CELA	CAMO	ATRO	ATCA X ATTR
CAMO	ATCA X ATID	ATTR X ATCA	ATRO		ATOB	ATAP	CELA
ATTR	CEPA		ATCA X ATID		KOPR 4	KOPR 7	
KOPR 4	ATAP	ATCA		ATAP		KOPR 12	ATCA
ATCA X ATCU	ATTR X ATCA	ATBO	ATAP	ATCA X ATID	ATCA X ATTR	ATOB	KOPR 4
CELA		KOPR 7	ATTR	CEPA	KOPR 12		ATTR
	ATCA	CELA	ATOB	ATRO	ATCA X ATCU	CAMO	ATGA
ATRO	ATGA		ATCA X ATCU	ATBO	ATID	ATBO	ATID
KOPR 12		CAMO	ATID	ATGA	KOPR 7		CEPA

Figure 49.—Field plot design for testing shrub adaptability on Blue Gate shale soil, Emery coal field. See appendix table 69 for plant symbol key.



Block #4		Block #3		Block #2		Block #1	
ATCA X ATTR	ATCA X ATID	ATCA	CEPA		ATCA		ATCA X ATCO X ATCA
ATCA X ATOB				ATRO		ATLA	ATCA
	ATLA	ATBO X ATTR	ATLA		ATCA	CEPA	ATCA X ATTR
	ATRO	ATCA X ATTR	ATRO	ATLA	CEPA		
CEPA	ATCA	ATCA	ATCA X ATCO X ATCA		ATCA X ATOB	ATBO X ATTR	ATCA X ATID
ATBO X ATTR	ATCA	ATFA	ATCA X ATID	ATBO X ATTR	ATCA X ATID	ATRO	ATCA
ATCA X ATCO X ATCA	ATFA	ATCA X ATOB		ATCA X ATCO X ATCA	ATCA X ATTR		ATCA X ATOB

Figure 50.—Field plot design for testing Atriplex *accessions on Persayo soil, Emery coal field. See appendix table 69 for plant symbol key.*

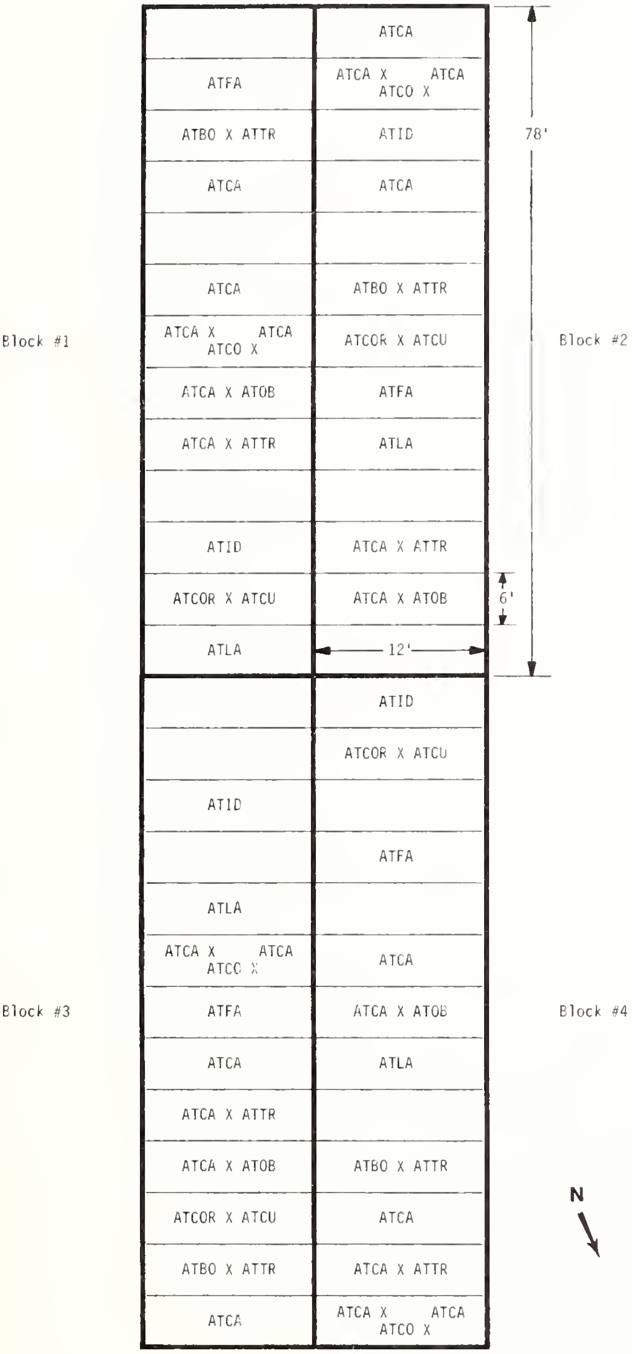


Figure 51.—Field plot design for testing Atriplex *accessions on Castle Valley soil, Emery coal field. See appendix table 69 for plant symbol key.*

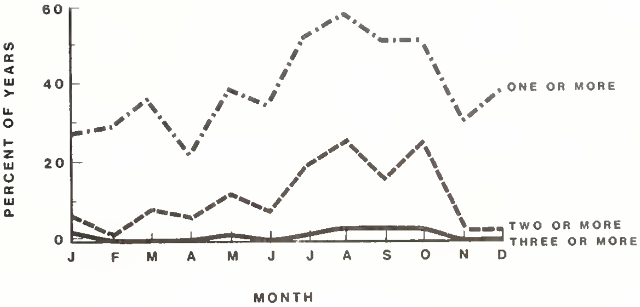


Figure 52.—Percent of past years in which each month had one or more, two or more, and three or more precipitation events of 0.4 inch or greater, Emery, Utah, 1922 to 1979.

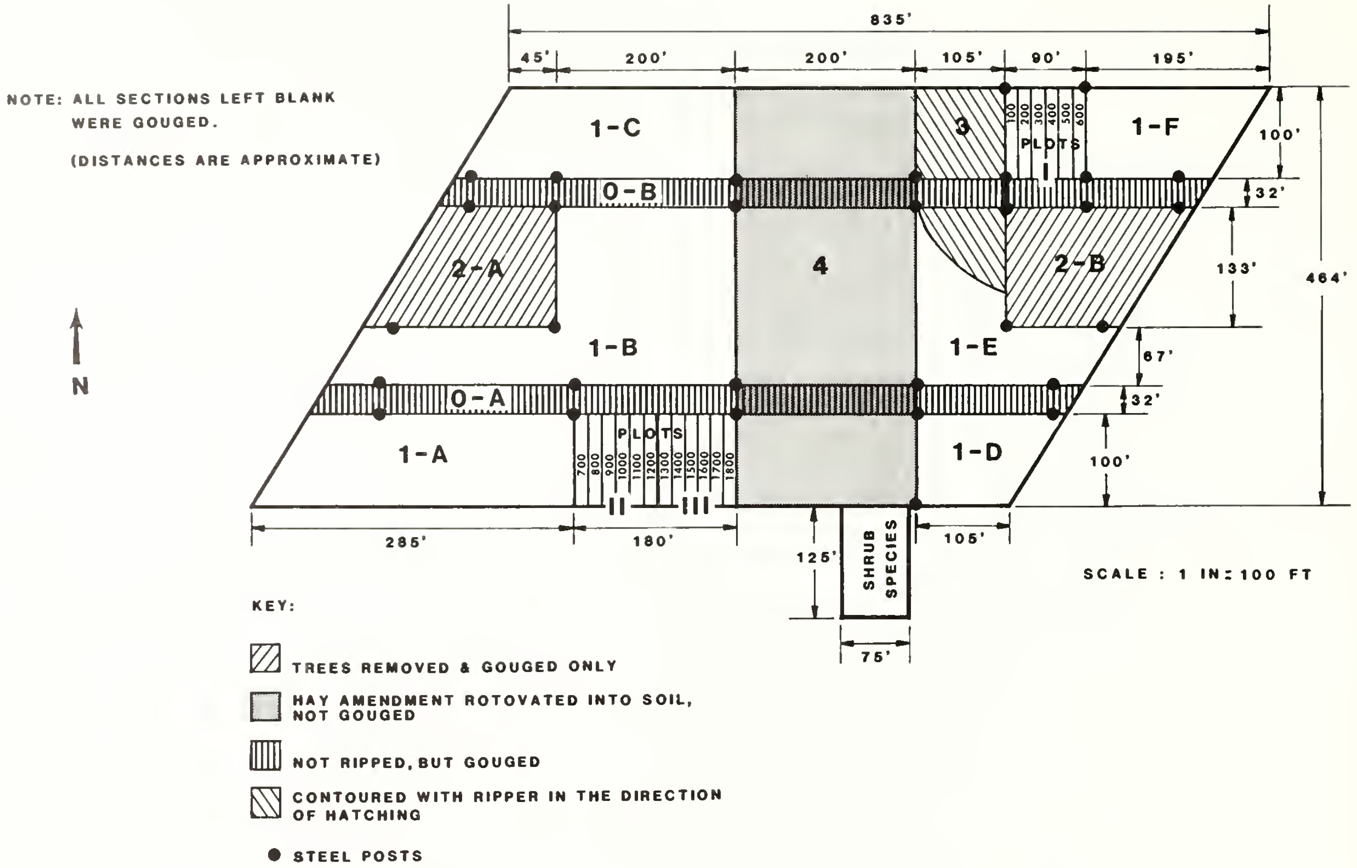


Figure 53.—Field plot design for the study of alternative site preparation methods on the 8-acre study site, Alton coal field.

Upper hillside block. Seeded Dec. 7, 1976

BLOCK I

100	200	300	400	500	600
AGRI	ELJU	AGSM	AGIN^2	AGTR^2	AGEL
AGIN^2	BRIN	ELCI	AGEL	AGEL	AGCR
AGEL	AGTR^2	AGRI	AGCR	AGCR	ELCI
ELJU	AGCR	ELJU	AGIN	AGSM	AGTR^2
AGIN	AGSM	AGTR^2	AGSM	AGIN	AGSM
ELCI	AGEL	BRIN	AGRI	AGRI	BRIN
BRIN	AGRI	AGEL	ELCI	ELCI	AGRI
AGCR	ELCI	AGCR	AGTR^2	AGTR^2	ELJU
AGSM	AGIN	AGIN^2	BRIN	BRIN	AGIN^2
AGTR^2	AGIN^2	AGIN	ELJU	ELJU	AGIN

Main Plot Treatments

BLOCKS	I	II	III
Topsoil (check)	500	800	1700
Topsoil + hay amendment	100	700	1800
" + compost amendment	300	1000	1400
Subsoil (check)	200	900	1600
Subsoil + hay amendment	600	1200	1500
" + compost amendment	400	1100	1300

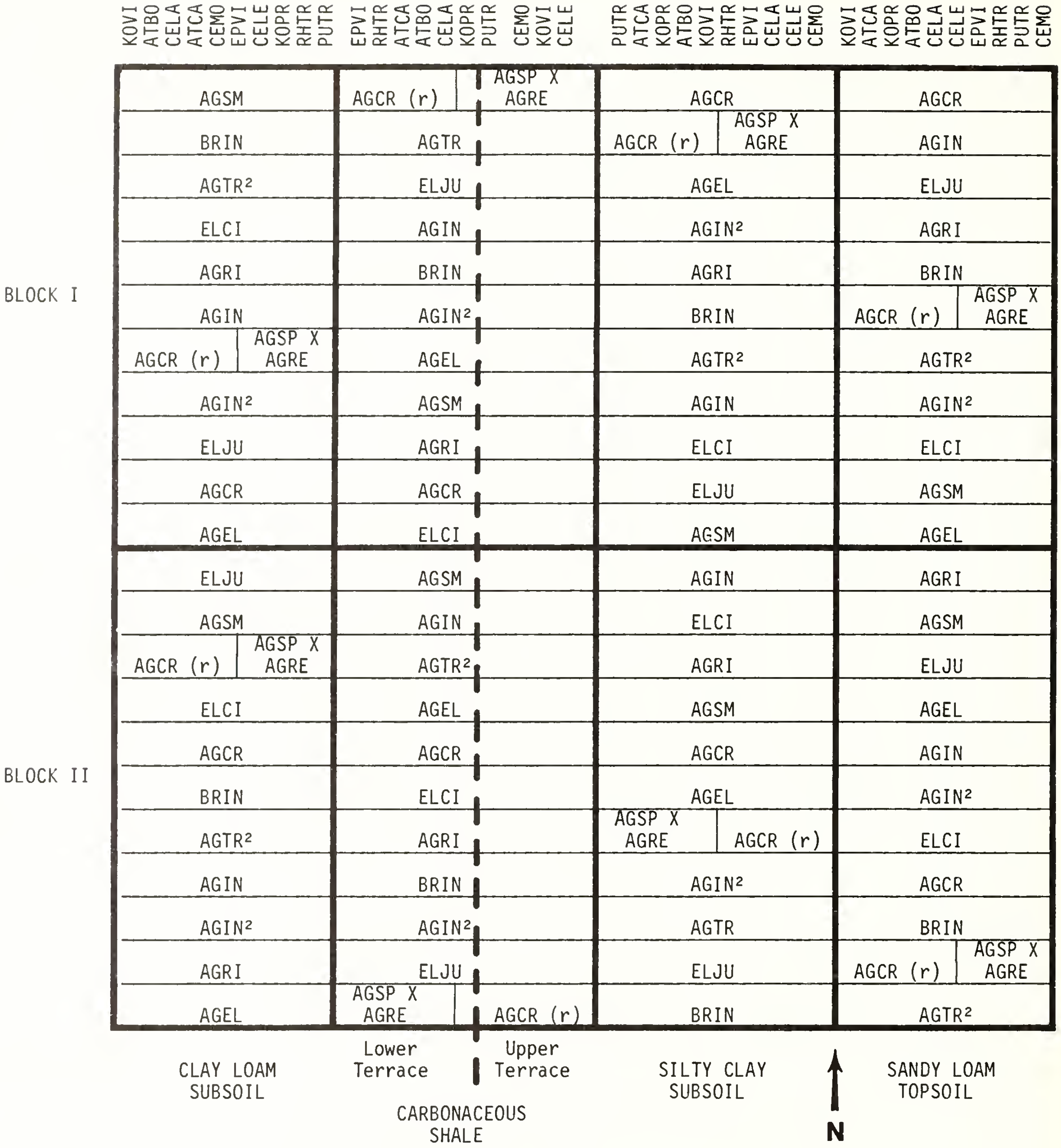
Subplot Species Symbols

AGCR	Agropyron cristatum (Fairway)
AGEL	Agropyron elongatum
AGIN	Agropyron inerme (Whitmar)
AGIN^2	Agropyron intermedium
AGRI	Agropyron riparium (Sodar)
AGSM	Agropyron smithii
AGTR^2	Agropyron trichophorum (Luna)
BRIN	Bromus inermis
ELCI	Elymus cinereus
ELJU	Elymus junceus

Lower hillside blocks. Seeded Dec. 7, 1976

BLOCK II						BLOCK III					
700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800
ELJU	AGCR	ELJU	BRIN	AGCR	AGRI	AGRI	AGCR	ELJU	AGRI	AGTR^2	ELCI
AGCR	AGRI	AGSM	ELJU	ELJU	AGEL	AGIN	AGEL	ELCI	AGEL	ELJU	AGEL
AGSM	AGEL	BRIN	AGCR	BRIN	AGTR^2	AGCR	AGRI	AGSM	AGIN^2	AGIN	AGTR^2
AGTR^2	ELJU	AGIN	AGIN	ELCI	ELCI	AGTR^2	BRIN	AGEL	AGSM	AGIN	AGCR
AGRI	AGIN	AGCR	AGEL	AGTR^2	BRIN	ELCI	AGIN	AGTR^2	ELCI	AGCR	AGIN
AGIN^2	BRIN	AGRI	AGSM	AGIN	AGSM	AGEL	ELJU	AGCR	ELJU	BRIN	AGSM
AGIN	ELCI	AGTR^2	AGRI	AGRI	ELJU	ELJU	AGSM	AGRI	BRIN	ELCI	BRIN
AGEL	AGTR^2	AGIN^2	AGTR^2	AGIN^2	AGIN	BRIN	AGTR^2	AGIN	AGCR	AGRI	AGIN
BRIN	AGIN	AGEL	ELCI	AGSM	AGCR	AGIN^2	ELCI	AGIN^2	AGTR^2	AGEL	ELJU
ELCI	AGSM	ELCI	AGIN^2	AGEL	AGIN^2	AGSM	AGIN^2	BRIN	AGIN	AGSM	AGRI

Figure 54.—Field plot design for the evaluation of organic soil amendments and different grass species on the 8-acre study site, Alton coal field. See appendix table 69 for plant symbol key.



	KOVI ATBO CELA ATCA CEMO EPVI CELE KOPR RHTR PUTR	EPVI RHTR ATCA ATBO CELA KOPR PUTR CEMO KOVI CELE	PUTR ATCA KOPR ATBO KOVI RHTR EPVI CELA CELE CEMO	KOVI ATCA KOPR ATBO CELA CELE EPVI RHTR PUTR CEMO
BLOCK I	AGSM	AGCR (r) AGSP X AGRE	AGCR	AGCR
	BRIN	AGTR	AGCR (r) AGSP X AGRE	AGIN
	AGTR^2	ELJU	AGEL	ELJU
	ELCI	AGIN	AGIN^2	AGRI
	AGRI	BRIN	AGRI	BRIN
	AGIN	AGIN^2	BRIN	AGCR (r) AGSP X AGRE
	AGCR (r) AGSP X AGRE	AGEL	AGTR^2	AGTR^2
	AGIN^2	AGSM	AGIN	AGIN^2
	ELJU	AGRI	ELCI	ELCI
	AGCR	AGCR	ELJU	AGSM
	AGEL	ELCI	AGSM	AGEL
BLOCK II	ELJU	AGSM	AGIN	AGRI
	AGSM	AGIN	ELCI	AGSM
	AGCR (r) AGSP X AGRE	AGTR^2	AGRI	ELJU
	ELCI	AGEL	AGSM	AGEL
	AGCR	AGCR	AGCR	AGIN
	BRIN	ELCI	AGEL	AGIN^2
	AGTR^2	AGRI	AGSP X AGRE AGCR (r)	ELCI
	AGIN	BRIN	AGIN^2	AGCR
	AGIN^2	AGIN^2	AGTR	BRIN
	AGRI	ELJU	ELJU	AGCR (r) AGSP X AGRE
	AGEL	AGSP X AGRE AGCR (r)	BRIN	AGTR^2
	CLAY LOAM SUBSOIL	Lower Terrace Upper Terrace CARBONACEOUS SHALE	SILTY CLAY SUBSOIL	SANDY LOAM TOPSOIL

Figure 55.—Field plot design for the study of grass species establishment and growth, and shrub survival and growth, on four soil materials at the 3-acre study site, Alton coal field. See appendix table 69 for plant symbol key.

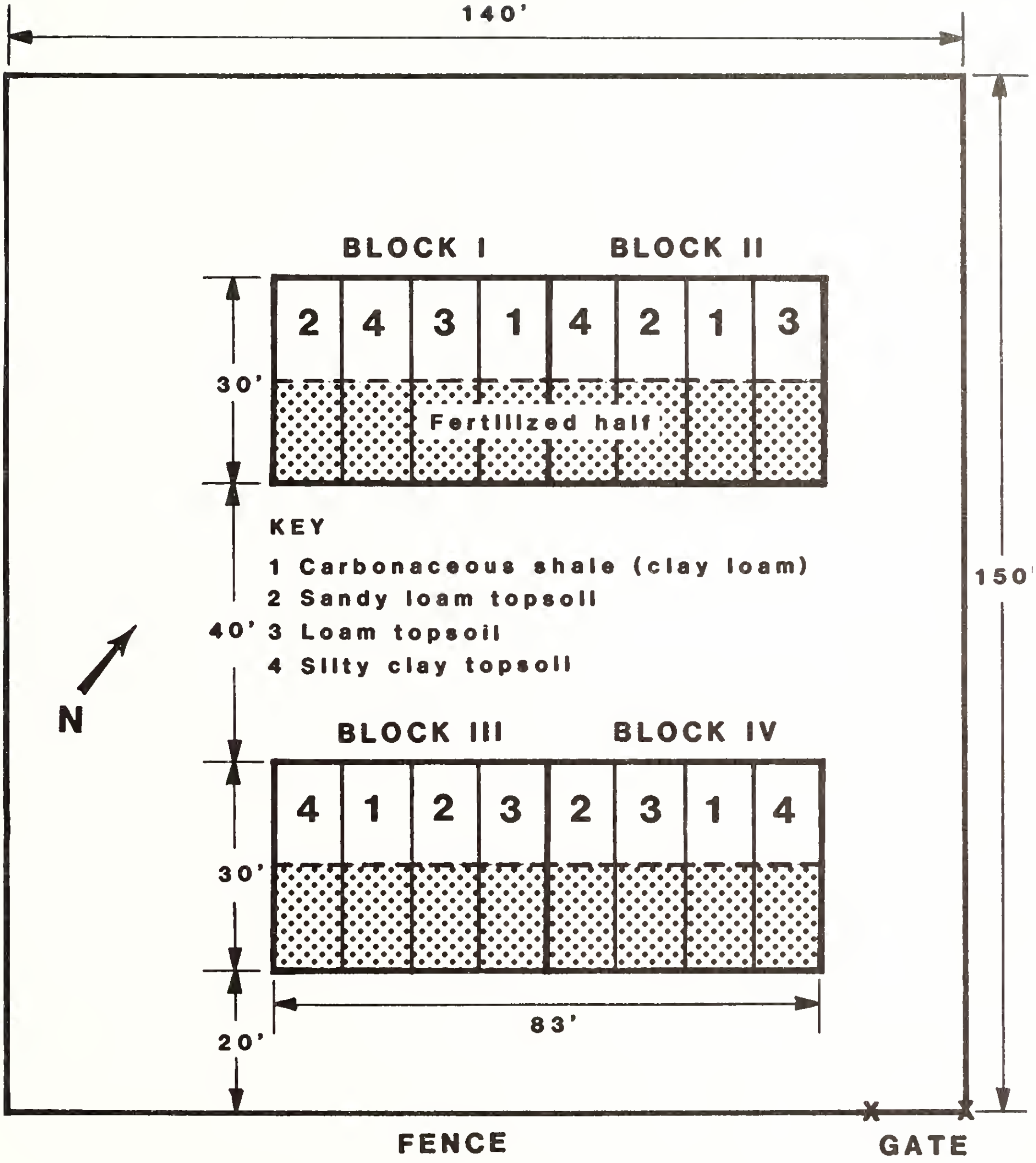
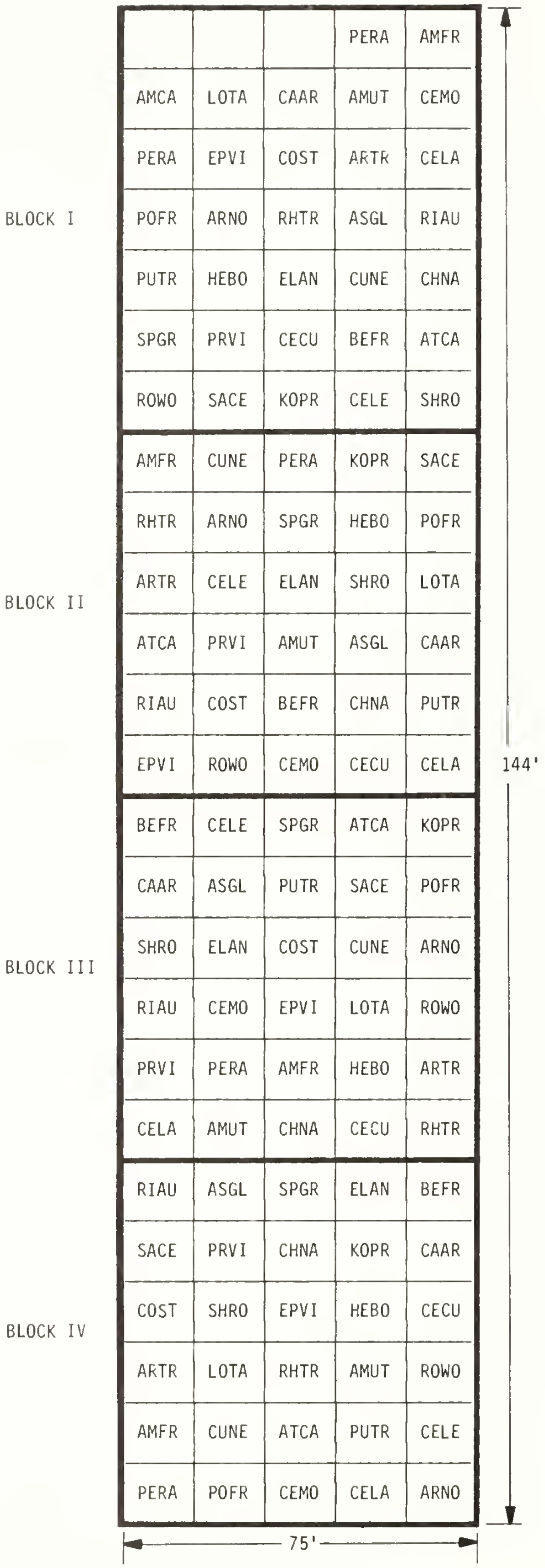


Figure 56.— Field plot design for the study of vegetation establishment on different topsoil-shale overburden combinations, Utah International cooperative study site, Alton coal field.



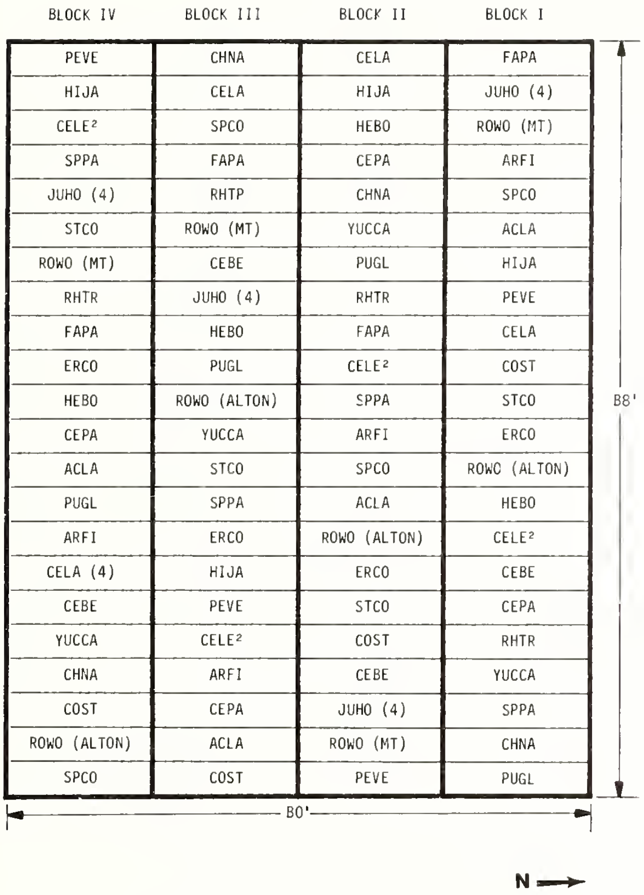
BLOCK I				PERA	AMFR
	AMCA	LOTA	CAAR	AMUT	CEMO
	PERA	EPVI	COST	ARTR	CELA
	POFR	ARNO	RHTR	ASGL	RIAU
	PUTR	HEBO	ELAN	CUNE	CHNA
	SPGR	PRVI	CECU	BEFR	ATCA
	ROWO	SACE	KOPR	CELE	SHRO
BLOCK II	AMFR	CUNE	PERA	KOPR	SACE
	RHTR	ARNO	SPGR	HEBO	POFR
	ARTR	CELE	ELAN	SHRO	LOTA
	ATCA	PRVI	AMUT	ASGL	CAAR
	RIAU	COST	BEFR	CHNA	PUTR
	EPVI	ROWO	CEMO	CECU	CELA
BLOCK III	BEFR	CELE	SPGR	ATCA	KOPR
	CAAR	ASGL	PUTR	SACE	POFR
	SHRO	ELAN	COST	CUNE	ARNO
	RIAU	CEMO	EPVI	LOTA	ROWO
	PRVI	PERA	AMFR	HEBO	ARTR
	CELA	AMUT	CHNA	CECU	RHTR
BLOCK IV	RIAU	ASGL	SPGR	ELAN	BEFR
	SACE	PRVI	CHNA	KOPR	CAAR
	COST	SHRO	EPVI	HEBO	CECU
	ARTR	LOTA	RHTR	AMUT	ROWO
	AMFR	CUNE	ATCA	PUTR	CELE
	PERA	POFR	CEMO	CELA	ARNO

SPECIES LIST

Planted June 14-16, 1977

AMFR	Amorpha fruticosa
AMUT	Amelanchier utahensis
ARNO	Artemisia nova
ARTR	Artemisia tridentata
ASGL	Astragalus globiceps
ATCA	Atriplex canescens
BEFR	Berberis fremontii
CAAR	Caragana arborescens
CECU	Ceanothus cuneatus
CELA	Ceratoides lanata
CELE	Cercocarpus ledifolius
CEMO	Cercocarpus montanus
CHNA	Chrysothamnus nauseosus
COST	Cowania stansburiana
CUNE	Cupressus nevadensis
ELAN	Elaeagnus angustifolia
EPVI	Ephedra viridis
HEBO	Hedysarum boreale
KOPR	Kochia prostrata
LOTA	Lonicera tatarica
PERA	Peraphyllum ramosissimum
POFR	Potentilla fruticosa
PRVI	Prunus virginiana
PUTR	Purshia tridentata
RHTR	Rhus trilobata
RIAU	Ribes aureum
ROWO	Rosa woodsii
SACE	Sambucus cerulea
SHRO	Shepherdia rotundifolia
SPGR	Sphaeralcea grossulariaefolia

Figure 57.—Field plot design for testing shrub and forb adaptability at the 8-acre study site, Alton coal field. See appendix table 69 for plant symbol key.



BLOCK IV	BLOCK III	BLOCK II	BLOCK I
PEVE	CHNA	CELA	FAPA
HIJA	CELA	HIJA	JUHO (4)
CELE[2]	SPCO	HEBO	ROWO (MT)
SPPA	FAPA	CEPA	ARFI
JUHO (4)	RHTP	CHNA	SPCO
STCO	ROWO (MT)	YUCCA	ACLA
ROWO (MT)	CEBE	PUGL	HIJA
RHTR	JUHO (4)	RHTR	PEVE
FAPA	HEBO	FAPA	CELA
ERCO	PUGL	CELE[2]	COST
HEBO	ROWO (ALTON)	SPPA	STCO
CEPA	YUCCA	ARFI	ERCO
ACLA	STCO	SPCO	ROWO (ALTON)
PUGL	SPPA	ACLA	HEBO
ARFI	ERCO	ROWO (ALTON)	CELE[2]
CELA (4)	HIJA	ERCO	CEBE
CEBE	PEVE	STCO	CEPA
YUCCA	CELE[2]	COST	RHTR
CHNA	ARFI	CEBE	YUCCA
COST	CEPA	JUHO (4)	SPPA
ROWO (ALTON)	ACLA	ROWO (MT)	CHNA
SPCO	COST	PEVE	PUGL

Figure 58.—Field plot design for testing shrub and forb adaptability, Utah International bulk sample site. See appendix table 69 for plant symbol key.

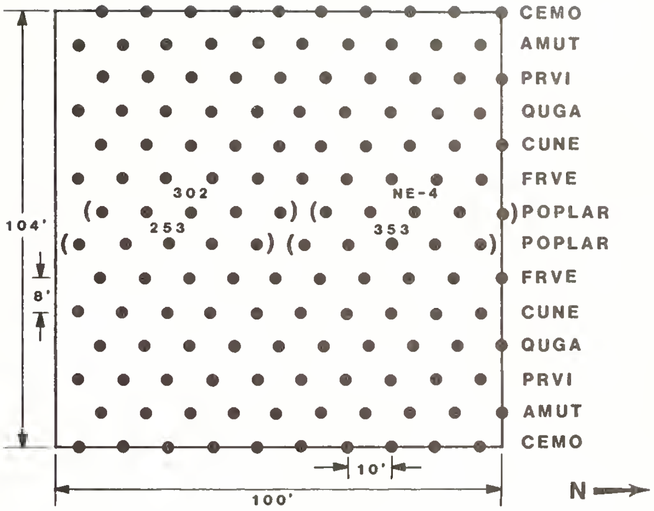
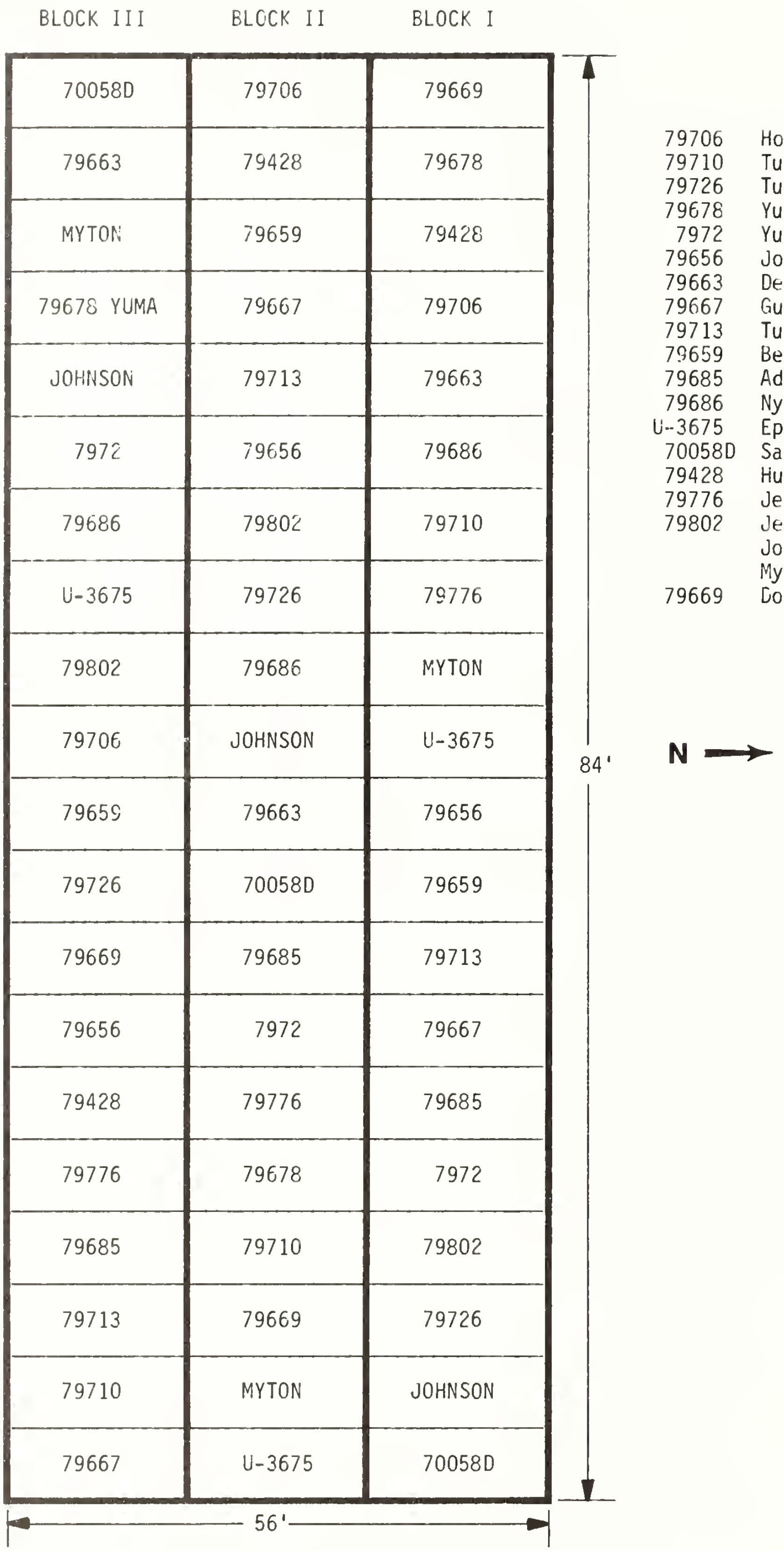


Figure 59.—Field plot design for the "windbreak" portion of the shrub adaptability test, Utah International bulk sample site, Alton coal field. See appendix table 69 for plant symbol key.



BLOCK III	BLOCK II	BLOCK I
70058D	79706	79669
79663	79428	79678
MYTON	79659	79428
79678 YUMA	79667	79706
JOHNSON	79713	79663
7972	79656	79686
79686	79802	79710
U-3675	79726	79776
79802	79686	MYTON
79706	JOHNSON	U-3675
79659	79663	79656
79726	70058D	79659
79669	79685	79713
79656	7972	79667
79428	79776	79685
79776	79678	7972
79685	79710	79802
79713	79669	79726
79710	MYTON	JOHNSON
79667	U-3675	70058D

ACCESSIONS LIST

79706	Holbrook, Navajo Co., AZ
79710	Tuba City, Coconino Co., AZ
79726	Tucson, Pima Co., AZ
79678	Yuma, Yuma Co., AZ
7972	Yuma (35 mi E), Yuma Co., AZ
79656	Joshua Forest, Riverside Co., CA
79663	Delta, Delta Co., CO
79667	Guaymas, Mexico
79713	Tularosa, Otero Co., NM
79659	Bernalillo, Sandoval Co., NM
79685	Adrian, Malheur Co., OR
79686	Nyssa, Malheur Co., OR
U-3675	Ephraim (Excel Canyon), Sanpete Co., UT
70058D	Sanpete Co., UT
79428	Huntington, Emery Co., UT
79776	Jericho sand dunes, Juab Co., UT
79802	Jericho sand dunes (gigas), Juab Co., UT
	Johnson Canyon, Kane Co., UT
	Myton, Duchesne Co., UT
79669	Douglas, Converse Co., WY

Figure 60.—Field plot design for testing Atriplex canescens *ecotypes, Utah International bulk sample site, Alton coal field.*

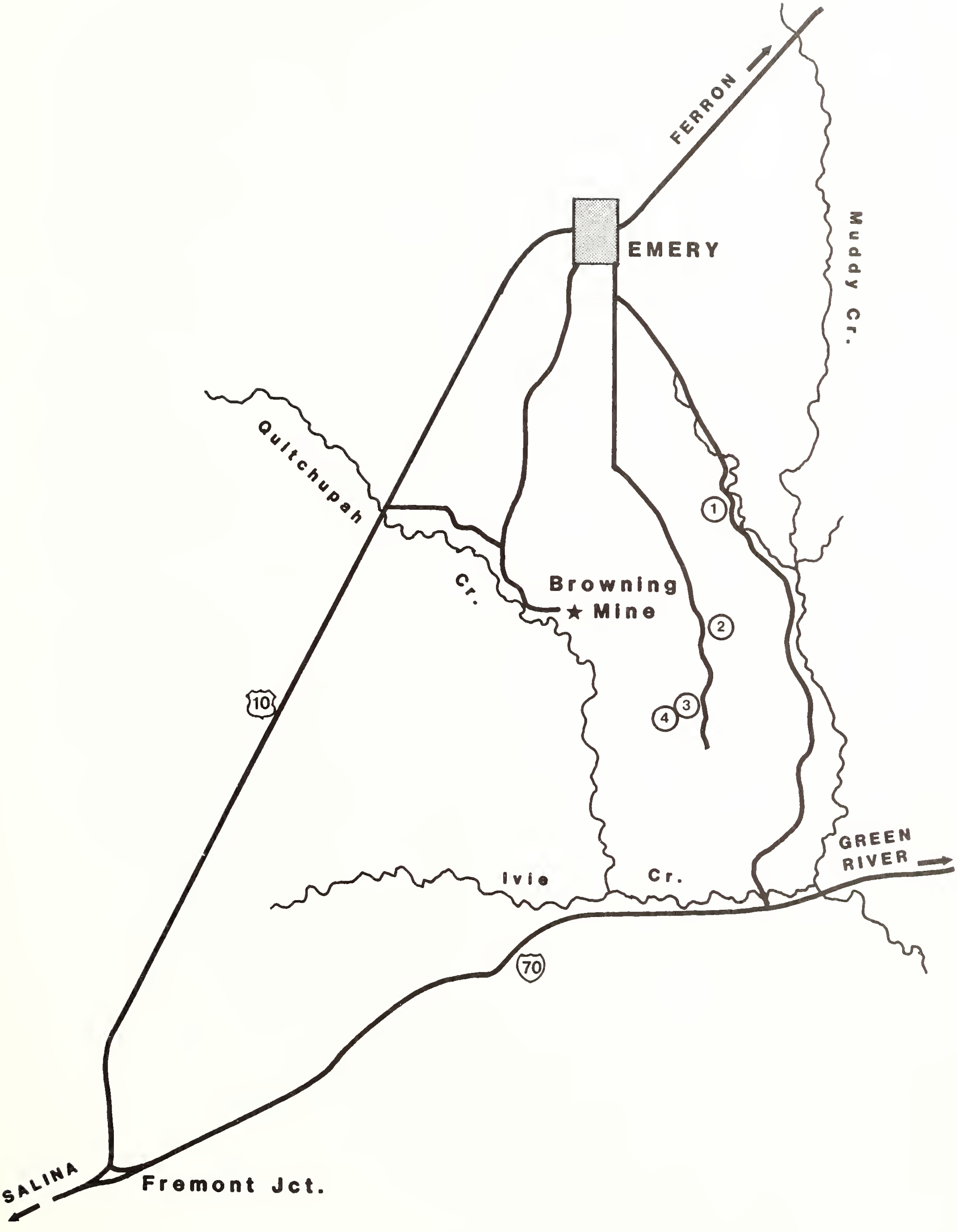


Figure 61.—Location of research sites near Emery, Utah: (1) Blue Gate, (2) Persayo, (3) Penoyer, and (4) Castle Valley.

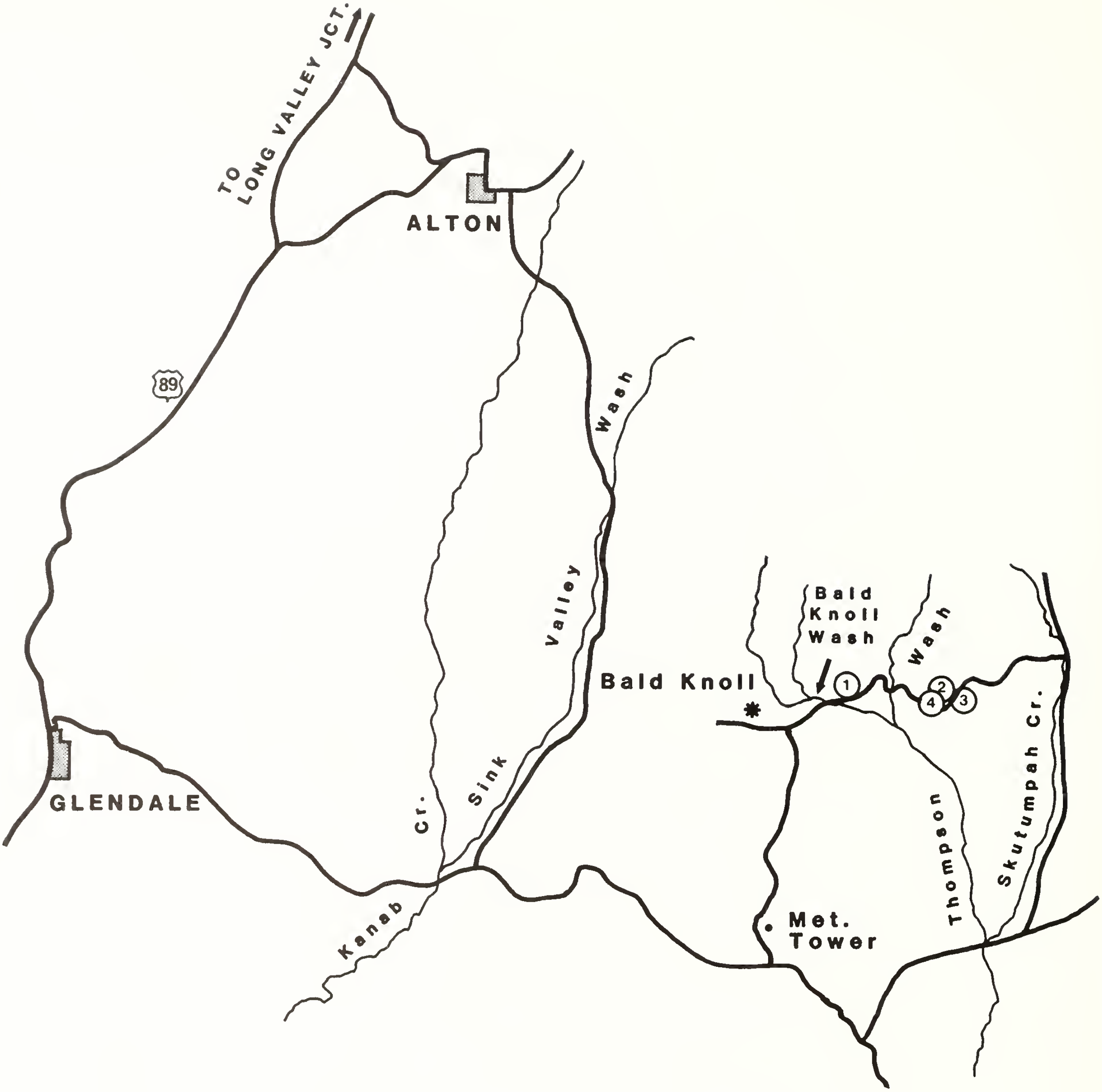


Figure 62.—Location of research sites on the Alton coal field: (1) Utah International, (2) 8-acre, (3) 3-acre, and (4) Utah International bulk sample site.

Ferguson, Robert B.; Frischknecht, Neil C. Reclamation on Utah's Emery and Alton coal fields: techniques and plant materials. Research Paper INT-335 Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 78 p.

Alternative methods of site preparation and broadcast seeding, in conjunction with soil amendments, were evaluated on severely disturbed soil materials of both coal fields during a 6-year study. Potentially useful plant species were planted and studied at several locations. Conclusions on a wide range of studies are presented.

KEYWORDS: coal, reclamation, revegetation, soil amendments, species adaptability, Utah, soil temperature, soil water potential, *Atriplex*, frequency sampling

The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Paper
INT-336

April 1985

Improving Voluntary Registration Through Location and Design of Trail Registration Stations

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CLEMSON UNIVERSITY
SEP 5 1985
PUBLIC DOCUMENTS

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ACKNOWLEDGMENTS

Adrienne Corti, volunteer, assisted the author with fieldwork. DeLynn C. Colvert, illustrator, USDA Forest Service, Missoula Equipment Development Center, provided consultation and artwork for experimental station signs.

RESEARCH SUMMARY

Poor registration rates at unattended trail stations have become a concern to managers who rely on such registration for information about wilderness use and users. Reliable data that accurately describe wilderness visitors and their use patterns allow managers to provide better opportunities for wilderness experiences and to better protect wilderness resources. This report describes an investigation of reasons that influence the visitor's willingness to register and whether compliance rates can be raised to useful levels.

A review of prior research showed that sign design (visibility and message), trail register maintenance, card design, and location of the trail register all influence compliance. Sign design and the location of the registration station were judged the two most important factors influencing registration. On this basis, a study of two different trail registration stations was conducted on three popular trails in the Bob Marshall Wilderness in Montana. A new sign was developed to depict both hikers and horse users registering and include a message about how the collected data were to be used. Effectiveness of this new sign was compared to the standard Forest Service sign currently used. Registration stations located at trailheads were compared with stations located 1 to 3 miles (1.6 to 4.8 km) up the trail.

Results showed location is the most important influence in improving registration rates. Moving the control sign from the trailhead up the trail almost doubled the registration rate. The experimental sign when moved up the trail raised registration from 50 percent to 69 percent. Separating the data by user type showed that visitors using horses and camping overnight responded well to the experimental sign up the trail. Registration was raised from 20 percent to 56 percent. Day hikers responded well to both the experimental and control signs up the trail (65 percent registered). Hikers who camped overnight had the highest registration of any group, with 88 percent registering in response to the experimental sign up the trail.

Selecting a good site for a registration station is a matter of judgment; however, the following criteria are universally useful: Signs should be visible for reasonable distances; the site should offer horse users a safe place to stop; the site should be placed where visitors are likely to stop for a rest, to drink, or to view some scenic attraction.

Improving Voluntary Registration Through Location and Design of Trail Registration Stations

Margaret E. Petersen

IMPORTANCE OF VISITOR REGISTRATION

Wilderness managers who understand visitors and their use patterns can provide better opportunities for wilderness experiences while protecting wilderness resources. Over the past two decades managers have relied extensively on voluntary registration to gain information about wilderness use and users. Information from registration stations can be used in workload planning and budgeting and has a variety of other uses. For example, knowledge of the user's primary method of travel is relevant to management decisions involving trail layout, design, and maintenance. The amount and distribution of use identifies trends that require increased management effort. Similarly, party size influences campsite management techniques and such knowledge may help in decisions about limits on party size. Information such as the visitor's Postal Service ZIP Code allows well-targeted informational campaigns. Because managers have needed and used information such as this, self-registration systems became a popular and inexpensive way to obtain information that would help in providing better wilderness experiences for visitors.

In the past, users have supplied the requested information at compliance rates believed to be fairly high. Early experimental studies in northwestern wildernesses examined visitor compliance with various trail register systems, and generally showed high response rates (Wenger 1964; Wenger and Gregersen 1964; James and Schreuder 1971; Lucas and Kovalicky 1981). Later studies, however, depict low and variable registration rates (Lucas 1983). For example, at seven trailheads in the Bob Marshall Wilderness, the overall compliance was 20 percent. This rate reflects low compliance by horse users, hunters, and day users and is not unique to the Bob Marshall. Because considerable variation in compliance among wildernesses exists (table 1), data from unmanned registers may be difficult to use.

When data not representative of the population of wilderness users are expanded, the resulting information is unreliable. Separate projections for each user type would improve reliability (Lime and Lorence 1974); however, very low compliance would not be useful for visitor use estimates.

Troxel (1981) suggested that voluntary registration be dropped if compliance rates could not be raised. A reliable information base is essential for good management decisions. Other methods, such as automated cameras,

Table 1.—Reported voluntary trail registration rates from 11 studies over 20 years (taken from: Lucas 1983)

	Areas	State	Year	Registration rate
				Percent
1.	Three Sisters Wilderness and Mountain Lakes Wilderness	Oregon	1961–62	74
2.	Mission Mountains Primitive Area	Montana	1968	65
3.	San Gorgonio Wilderness	California	1969	77
4.	Rawah Wilderness	Colorado	1970	89
5.	Selway–Bitterroot Wilderness	Montana	1974	28
6.	Idaho Primitive Area	Idaho	1974	18
7.	Sawtooth Wilderness	Idaho	1975	78
8.	Waterton Lakes National Park	Alberta	1976	78
9.	Spanish Peaks Primitive Area	Montana	1977	50
10.	McCormick Forest	Michigan	1978–79	67
11.	Bob Marshall Wilderness	Montana	1981	20

photoelectric traffic counters, pressure-plate counters, and observers stationed along trails, provide information about wilderness visitors. Nevertheless, trail registration stations have the potential to provide considerably more information (such as direction of travel, intended destination, length of stay, residence, number in group), operate at all times. and are less expensive to establish and service (Echelberger and others 1981). Given the costs of other methods, it is worthwhile to examine reasons for noncompliance in the voluntary registration system and determine if compliance rates could be increased to a useful level. The literature was searched to identify factors that influence visitor registration. This done, two factors of special significance (station location and sign design) were selected for experimental manipulation to determine the true influence of each and to determine if compliance could be raised to satisfactory percentages.

FACTORS THAT INFLUENCE REGISTRATION RATES

Registration depends on the visitor's willingness to take the time and effort to fill out a questionnaire. To be successful, a message requesting the visitor to do this must be effectively communicated. The visitor must believe registering is worth the effort. Sign visibility, message, maintenance, card design, and location all influence the visitor to register.

Sign Visibility

Historically, signs have been designed to fit the "wilderness experience," which seems to include muted colors and rustic designs. Registration stations that seem too "commercial" may offend users (Lucas and Oltman 1971); however, it is possible that the standard Forest Service sign is so unobtrusive that it fails to catch the visitor's attention. The color and the placement of the trail sign need to be such that the visitor cannot miss it (Lucas and Kovalicky 1981). The horse user must see the sign in time to make a controlled stop before reaching the registration station. A sudden stop with a pack string may be dangerous. User awareness of the sign is also dependent on an adequate sight distance along the trail, which will be discussed later.

Sign Message

Although sign color influences visibility, the message itself is probably of greater importance. It has been found that even a lack of information influences visitors (Brown and Hunt 1969). Both horse users and hikers we talked to suggested that there is a need for registration information to be explained more fully. Leatherberry and Lime (1981), in a study in Wisconsin, found that hikers thought that the sign message should explain the need for registering. Although sign wording varied in their study, depending on whether the permits were voluntary or mandatory, the basic message was "please register." Nearly half of the Wisconsin users queried felt that compliance would be improved if the sign explained the purpose of registration and use of the information. Wenger (1964) found that signs without explanation elicited more "junk" (nonsensical lines, lewd comments, etc.), which may have been due to a lack of understanding of the purpose of registration. Users apparently do not reread the sign on each visit, so it is critical that the message be effective on the first reading. When registration is voluntary, most visitors will register if they believe it is worth their time and effort.

Station Condition

The effect of poor maintenance of registration facilities is unknown, but it is probably significant in reducing the registration rate. Lack of supplies, such as pencils and cards, will prevent users from complying and will give visitors a negative impression of the managing agency's data collection effort. In the absence of supplies, some visitors have tried to register by using their own pencils and scraps of paper (Lucas 1983).

Registration Card Design

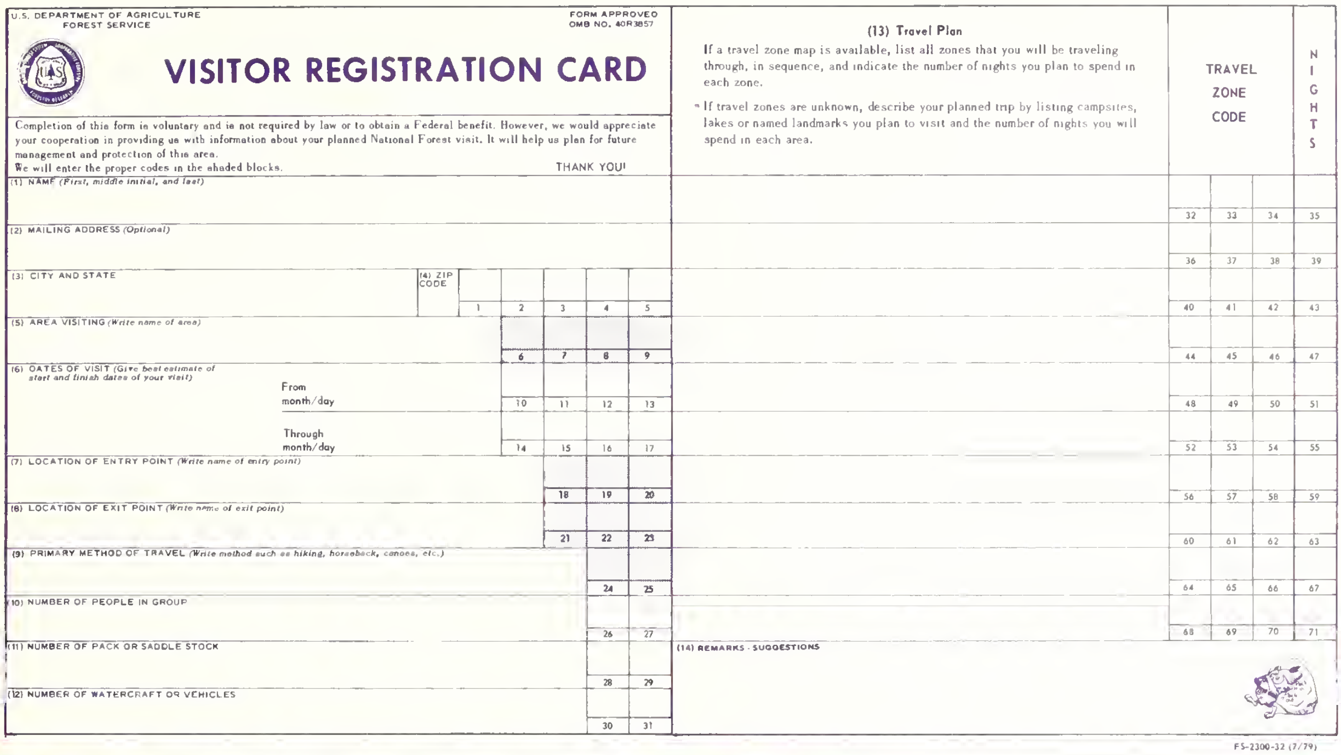
The visitor registration cards, which are standardized and used nationally, may contribute to poor registration rates and inaccurate information. The card can confuse visitors because of awkward questions and small print size (fig. 1). In addition, some of the questions may be irrelevant to the specific wilderness and the manager's interests.

Many visitors fill out only the first few lines of the registration card. Therefore, the most important information—party size, length of stay, and destination—should be asked before name and address (questions 1 through 3 on the card). Then, even partially filled-out cards will supply the most vital information. If the geographical distribution of the visitors is needed, visitors could supply their Postal Service ZIP Code near the end of the card. The standard form asks visitors "location of entry point" (question 7). Stamping the name of the trailhead on the card would eliminate visitor responses such as "here" and ensure that the entry point is correct.

Question 12 asks visitors "number of watercraft or vehicles." This is inapplicable to most wildernesses and should be eliminated where inappropriate. Allowing managers to design their own registration cards would enable them to ask relevant questions and would minimize visitor annoyance.

Half of the registration card is devoted to the visitor's travel plan (question 13). Visitors are requested to code their travel zones from a map that is not present at trailheads. The visitor may therefore infer that the agency is not seriously collecting data. As a result, most visitors do not fill out half of the card. This section of the card could be eliminated. If travel information is desired, it may be gathered more accurately by wilderness rangers through conversations at trailheads, along trails, or at campsites.

Removing the travel information, rewording or eliminating awkward questions, and allowing managers to incorporate questions more relevant to their wilderness would greatly improve the registration card. The most important questions should be answered first. All questions should be printed in a large block type for easier



U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

FORM APPROVED
OMB NO. 40R3857

VISITOR REGISTRATION CARD

Completion of this form is voluntary and is not required by law or to obtain a Federal benefit. However, we would appreciate your cooperation in providing us with information about your planned National Forest visit. It will help us plan for future management and protection of this area.
We will enter the proper codes in the shaded blocks. THANK YOU!

(1) NAME *(First, middle initial, and last)*

(2) MAILING ADDRESS *(Optional)*

(3) CITY AND STATE

(4) ZIP CODE 1 2 3 4 5

(5) AREA VISITING *(Write name of area)* 6 7 8 9

(6) DATES OF VISIT *(Give best estimate of start and finish dates of your visit)*
From month/day 10 11 12 13
Through month/day 14 15 16 17

(7) LOCATION OF ENTRY POINT *(Write name of entry point)* 18 19 20

(8) LOCATION OF EXIT POINT *(Write name of exit point)* 21 22 23

(9) PRIMARY METHOD OF TRAVEL *(Write method such as hiking, horseback, canoes, etc.)* 24 25

(10) NUMBER OF PEOPLE IN GROUP 26 27

(11) NUMBER OF PACK OR SADDLE STOCK 28 29

(12) NUMBER OF WATERCRAFT OR VEHICLES 30 31

(13) Travel Plan

If a travel zone map is available, list all zones that you will be traveling through, in sequence, and indicate the number of nights you plan to spend in each zone.

* If travel zones are unknown, describe your planned trip by listing campsites, lakes or named landmarks you plan to visit and the number of nights you will spend in each area.

TRAVEL ZONE CODE			NIGHTS
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71

(14) REMARKS - SUGGESTIONS

FS-2300-32 (7/79)

Figure 1.—Voluntary self-registration card currently used in the Bob Marshall Wilderness, MT.

reading. Changing the card's format and size would greatly improve the quality and accuracy of visitor responses.

Station Locations

Wenger (1964) and others have suggested that station location influences registration rates. Locations up the trail from the trailhead may be superior to parking lot placement in improving compliance. Lucas and Kovalicky (1981) discussed potential reasons for selecting locations up the trail (as opposed to the trailhead location). Their reasons were (1) signboards may be unnoticed at the trailhead because of cars, bulletin boards, and other related distractions; (2) the group leader is generally the one who registers and his attention will be focused on getting everything ready while at the trailhead; (3) users may welcome a place up the trail to adjust saddles and backpacks; (4) the registration system placed up the trail may symbolize wilderness entry; and (5) a registration system up the trail will screen out users making very brief trips.

When evaluating location, one should also consider factors such as trail slope, trail grade, and turnout space for stock. Visitors should see the sign from a distance; registration stations therefore should not be located on bends in the trail. Users may be more likely to register if registration stations are placed in attractive, accessible, and highly visible areas.

STUDY OF STATION MODIFICATIONS

Based on the literature review, it was concluded that sign design and location did indeed affect rates of compliance and thus offered a promising means of raising registration rates. It was decided to test variations in location and design on trails typical of those used by wilderness visitors. Specific objectives were to determine: (1) how much location and sign design affect nonoutfitted party registration, and (2) whether rates could be raised sufficiently to be useful for management planning.

Study Area

The Bob Marshall Wilderness in Montana is 1,009,356 net acres (408 481 ha) in size and is contiguous to the Great Bear and Scapegoat Wildernesses. Together the three wildernesses total over 1,535,000 net acres (over 621 000 ha) (fig. 2). The area offers large rivers suitable for rafting and fishing, and lowland valleys, along with high mountain vistas. The composition of users is about 40 percent horse users and 60 percent hikers. About 17 percent are outfitted groups. Average length of stay is about 5 days (Lucas, in press), which is longer than other wilderness areas in Montana. In 1983, visitor use of the three-wilderness complex totaled 215,000 visitor days. The area has over 70 trailheads and an extensive trail system. Trail registers are present on most trails.

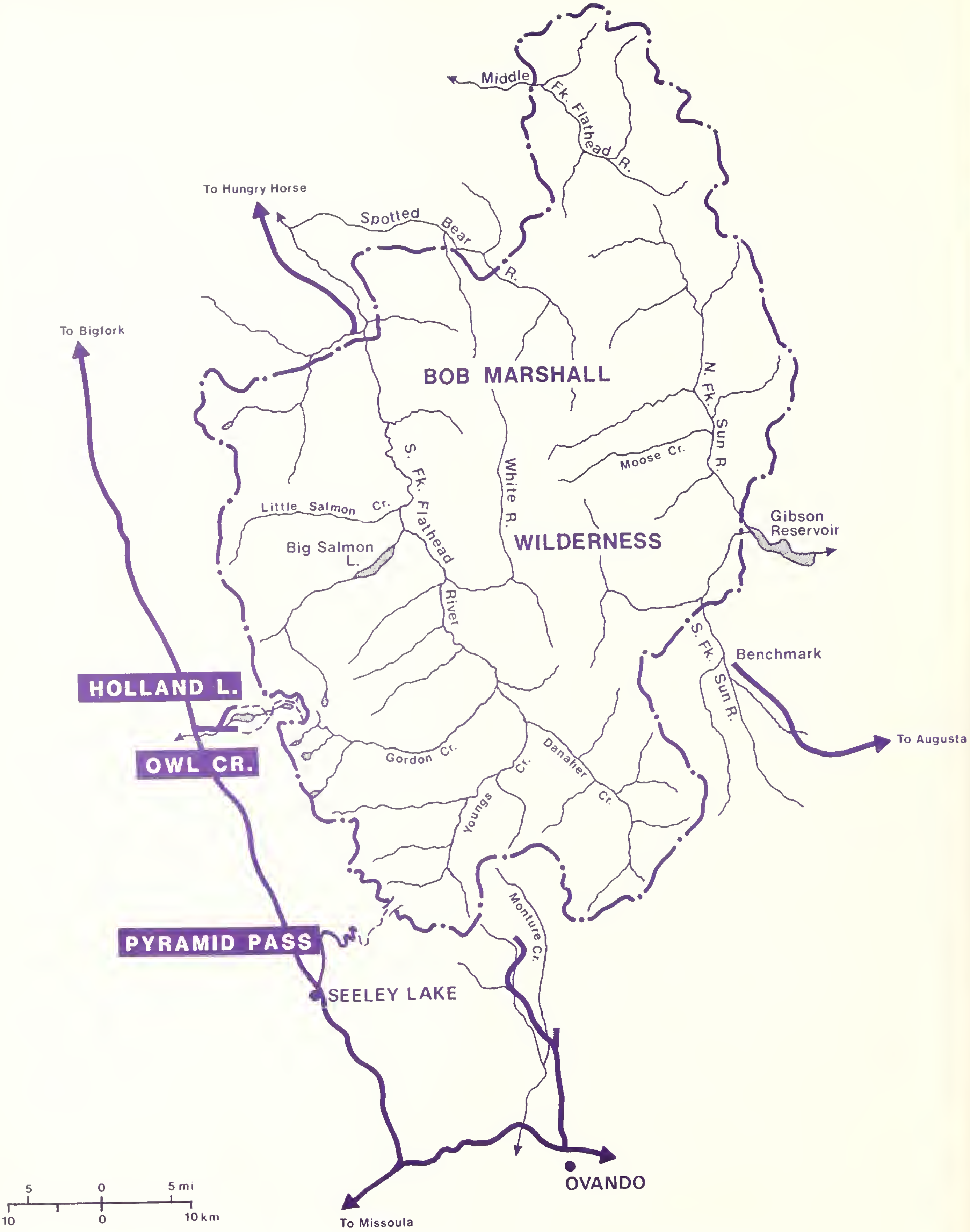


Figure 2.—Bob Marshall Wilderness.

Selection of the Signs

Two signs were evaluated: the Forest Service sign currently in use, which served as a control, and an experimental sign developed especially for this study (fig. 3).

For the experimental sign, a high-visibility orange and black design was developed in cooperation with a local wilderness user group and the Missoula Equipment Development Center. The sign selected depicts both horse and hiker parties registering (fig. 3). This picture appeals to all types of users and provides a nonverbal message to parties actually registering. The main caption (the first third of the sign) reads: "One person from each party please register here when entering this area." The last part of the sign reads:

"We need your help to:
  Plan trail & campsite maintenance
  Measure use & effect
  Plan management budgets."

Station Locations

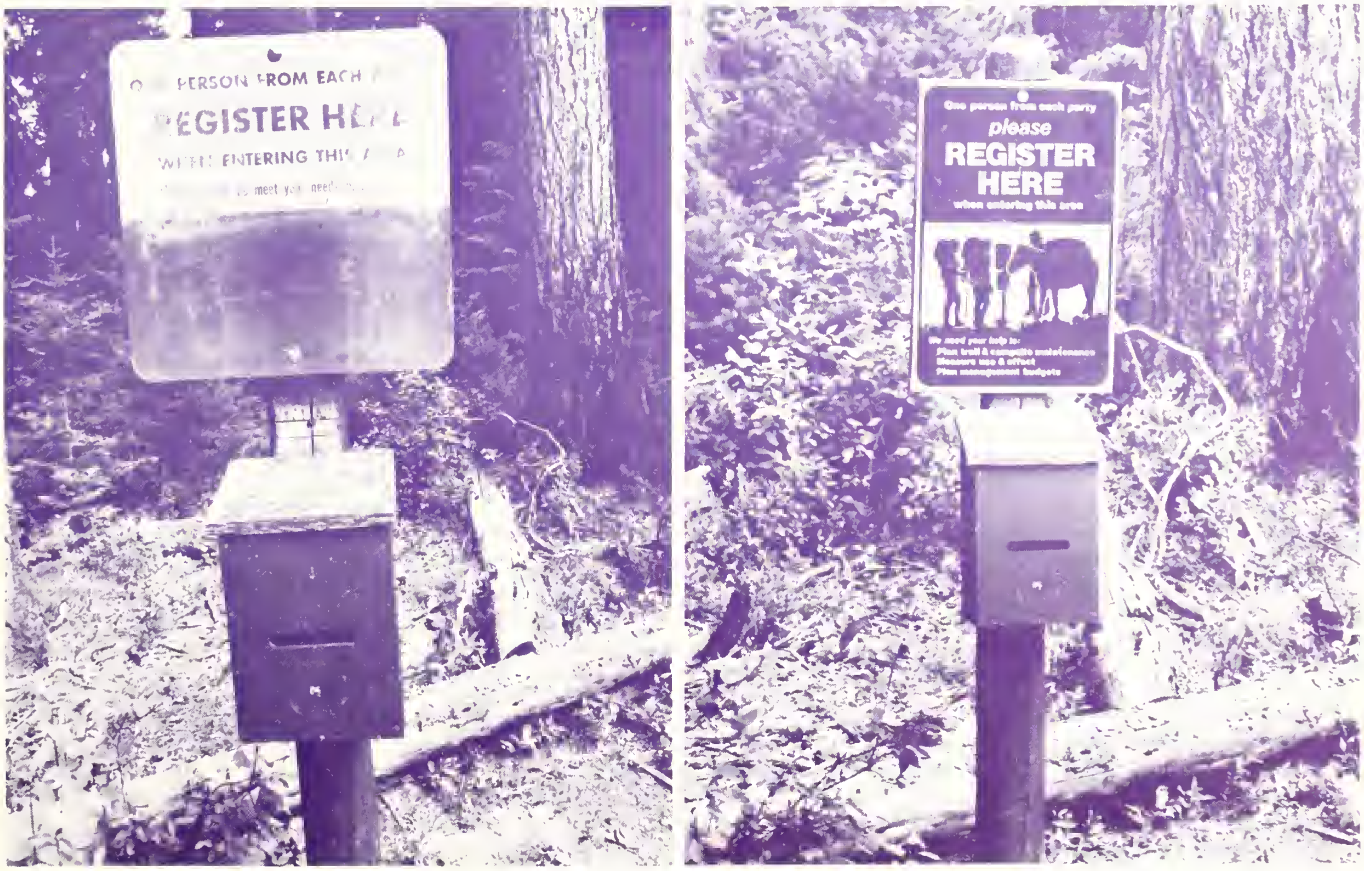
Two locations for sign placement were tested: (1) the current location at or close to the trailhead, and (2) a site 1 to 3 miles (1.6 to 4.8 km) up the trail. The actual selection of the up-trail location depended on factors such as the registration station's placement on the trail, secondary conditions at the location, trail tread conditions, and local attractions such as scenic vistas.

Field Procedures

Three sign and location combinations were tested for their potential to improve registration rates. They were compared against the control, the original registration station at its original location (OSOL). The three combinations tested were the original registration station at a new location 1 to 3 miles (1.6 to 4.8 km) up the trail (OSNL), the new registration sign located at the original location (NSOL), and the new registration sign at the new location 1 to 3 miles (1.6 to 4.8 km) up the trail (NSNL).

The Holland Lake trail, Owl Creek trail, and Pyramid Pass trail were selected as study sites. The trails received some of the highest use (Lucas 1983), their locations minimized study travel costs, and users included a high percentage of horsemen (fig. 2). Owl Creek attracts a high proportion of outfitters who were excluded from the study because they file trip plans with the Forest Service and are generally not expected to register.

In order to determine the success of any of the sign and location combinations, it was decided that the minimum useful compliance rates would be 60 percent for private overnight hiker parties and 50 percent for overnight horse parties. With such rates, and in conjunction with knowledge of the different user groups' registration rates, expanded data should be acceptably reliable. Any combination that provided these compliance rates would be viewed as successful.



Control Sign

Experimental Sign

Figure 3.—Control and experimental signs.

The study period began June 30 and ended October 20, 1982. This time period was blocked into two periods using August 15 as the midpoint so that each of the combinations would be replicated. Within a block, the four combinations were randomly assigned to four time intervals, ranging from 10 to 14 days. The combinations did not occur concurrently on any of the trails and were never placed back to back, which would have resulted in one combination running for 20 to 28 days. Each time interval included weekends or holidays when peaks in visitor use were expected. Because visitor awareness of the project could affect registration behavior, days on which the signs were to be changed or relocated were scheduled for the middle of the week when there were fewer visitors.

Data Collection

Private party registration was determined by comparing registration cards and outfitter schedules against a photographic record that recorded actual use and registration behavior. The registration cards and outfitter schedules were tabulated simultaneously with the film to minimize confusion resulting from inaccurate information. This worked better than tabulating each separately. Registration cards were used to verify parties registered. Outfitter schedules were used to help identify and eliminate nonregistering commercial parties from the data.

The film record was obtained from a camera system developed by the USDA Forest Service Equipment Development Center in Missoula, MT (Gasvoda 1978). An electronic trail traffic counter and camera were affixed to trees 25 to 40 yards (23 to 36 meters) back from the registration station. When the traffic counter infrared beam was broken by a visitor, the camera was triggered to expose two frames. At the 2-mile (3-km) location on Pyramid Pass, placement and camouflage problems prevented focusing on the registration station. At this location, the camera was moved about 100 yards (91 meters) down the trail. Visitors could be counted on their way up to the station, but registration behavior could not be observed and was inferred.

RESULTS AND DISCUSSION

Registration rates were influenced by location of the registration station when all trails and user groups were considered together (table 2). Moving the control sign from the trailhead to a new location up the trail almost doubled the registration rates. The experimental sign, when located up the trail, resulted in a registration rate of 69 percent, compared to 50 percent at the trailhead. For signs at the farthest location, compliance rates were 60 percent for the control sign and 69 percent for the experimental sign. This difference is small, and is the only comparison that is not highly significant statistically (table 2). Registration rates must be examined separately by user groups, however, before a decision to develop a new sign for up-trail locations can be made.

When data from all three trails were combined, and the different types of user groups separated out, the new sign farther up the trail ranked first for all users except day horse riders (table 3). The day horse-user category had so few observations that it was difficult to judge which sign and location combination worked best with this type of visitor.

Day Hikers

Day hikers responded very well to both signs located up the trail. The new sign received 65 percent compliance while the old sign received 64 percent. Location influenced the day hiker's registration rate more strongly than either sign design. The new sign at the trailhead did not elicit a high registration rate (44 percent), although this was almost twice the rate for the old sign at the trailhead. Day hikers may not consider themselves as wilderness visitors and may not feel motivated to register at the trailhead for this reason. For this group, seeing the registration station farther in the wilderness may indeed symbolize wilderness entry (Lucas and Kovalicky 1981), and they respond favorably to registering. Of course, some day hikers may never reach the registration station if it is located far up the trail, but other monitoring techniques can be used to measure this use if it is important.

Table 2.—Combined registration data from Pyramid Pass, Owl Creek, and Holland Lake trails[1] for all visitor types

Item	Treatment A OSNL[2]	Treatment B OSOL[2]	Treatment C NSNL[2]	Treatment D NSOL[2]
Number of parties	110	198	135	130
Number registered	66	64	93	65
Percent registration	60	32	69	50

[1] Statistical significance, tested by χ^2:
1. Old sign by location (treatments A and B) ($\chi^2 = 22.2$, df = 1, $p < 0.001$)
2. New sign by location (treatments C and D) ($\chi^2 = 9.8$, df = 1, $p < 0.005$)
3. Old location by sign (treatments B and D) ($\chi^2 = 10.3$, df = 1, $p < 0.005$)
4. New location by sign (treatments A and C) ($\chi^2 = 2.1$, df = 1, $p < 0.20$).

[2] OSNL = old sign, new location
OSOL = old sign, old location
NSNL = new sign, new location
NSOL = new sign, old location.

Table 3.—Total number of parties and percentage registration by type of user group for three trails combined[1]

	Overnight				Day			
	Hikers		Horse		Hikers		Horse	
Sign treatment	No. of parties	Percent	No. of parties	Percent	No. of parties	Percent	No. of parties	Percent
OSNL	40	83	20	20	42	64	8	25
OSOL	60	57	5	20	124	23	7	0
NSNL	52	88	41	56	31	65	7	14
NSOL	38	76	20	45	57	44	11	9

[1] Statistical significance, tested by χ^2:

1. Overnight hikers by treatment ($\chi^2 = 16.9$, df = 3, $p < 0.001$)
2. Overnight horse by treatment ($\chi^2 = 8.3$, df = 3, $p < 0.04$)
3. Day hikers by treatment ($\chi^2 = 34.4$, df = 3, $p < 0.001$)
4. Day horse by treatment (NA).

Overnight Horse Users

Overnight horse users responded well to the new sign farther up the trail, with a 56 percent registration rate. The old sign up the trail did not do as well (20 percent). The old sign at the trailhead also elicited only 20 percent compliance from a small sample, compared to 45 percent for the new sign at the trailhead. Registration rate is clearly affected by design of the station for this particular user type.

Overnight Hikers

Overnight hikers had the highest registration rates of any user group. Eighty-eight percent complied with the new sign up the trail, with 83 percent registering at the old sign in the same location. Even the two sign combinations at the trailhead received acceptable registration rates. Seventy-six percent registered at the new sign and 57 percent complied at the original sign. With only 5 percent difference between the two best ranked combinations, it appears that location is a more important factor than design in attracting better registration rates from overnight hikers.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

For all user categories, it is interesting that the old sign and trailhead location ranked last. Any modification of the current system appears to improve visitor compliance, and the best system, the new sign at the new location, was over twice as effective as the current system. Perhaps visitors noticed more managerial interest reflected in station maintenance, which improved their perception of the usefulness of the information they provided. The new sign was more visible and simply may have attracted more attention. Location, however, generally appeared to have the strongest influence on compliance.

Location is clearly important for achieving useful registration rates. Locations up the trail may elicit desired response because visitors are now ready to stop. This highlights how important location choice is when establishing sites. Visitors also may have discharged some of the pretrip energy and can now think of other things besides loading up and getting on the trail.

The sign and its message influenced visitor registration, but not generally as strongly as location. It appears the brief "please register" is almost as effective as the more detailed message, perhaps because visitors were ready to register. Nevertheless, the importance of the message and sign design cannot be underestimated, because user groups respond differently. For example, the new sign up the trail received a 56 percent registration rate from overnight horse users. This is 36 percent higher than that from the old sign in the same location, and may result from horse users identifying with the horse user in the picture, as suggested by the relatively high rate for the new sign at the old location. Improving the rate to 56 percent can be valuable to managers. At this level, expanding the use figures can produce acceptably reliable estimates suitable for workload planning.

By manipulating sign and location, overnight hikers, overnight horse users, and day hikers were induced to register at rates sufficient for reliable use estimates. The small sample of day horse users responded poorly, and thus their significance in the visitor impact pattern must be examined. During the entire study period, day horse parties accounted for less than 6 percent of the visitor parties. At such low percentages, managers may decide to gain information about them through other monitoring techniques. Cameras, field counts, and the like, are all useful alternative methods to registration stations, and may provide cheaper, more useful information. Conversely, hikers comprised 77 percent of the observed visitor parties, over half of which were day users. Failure to register half of this group would be a serious loss of data.

If registration stations are to be used, one must allow sufficient time to select good sites. Many factors, large and small, must be considered. For this study, two people spent a half day examining possible sites and selecting the best one. A good site, located farther up the trail than a poorer one, may cost more to service, but may be worth it in better information produced. Perhaps not all trails need registers, at least for use measurement. Registers placed along a few high-use trails may be all that is needed to learn about most of the visitors to the area.

Selecting a good trail registration site is judgmental, but the following criteria are suggested for site selection:

1. Is this a site where most users would be likely to catch their breath or adjust saddles?
2. Does the site offer a point of interest, scenic view, or stream crossing where most visitors would naturally stop?
3. Can horse users stop safely in the trail? Is the trail narrow enough that a pack string can be contained?
4. Can the station be serviced with a reasonable expenditure of time and money?
5. Is the location far enough up the trail that pack strings will be settled down and easy to control?
6. Does the registration station stand away from other signs, such as directional pointers, that may distract the visitor from the registration message?
7. Can the sign be seen easily by approaching visitors who are unfamiliar with the area?

This study examined three trails in the Bob Marshall Wilderness. The trails are typical of wilderness trails with substantial horse and hunter use; therefore, the results probably would be generally similar elsewhere, at least in relative effectiveness of the alternative signs and locations. Although the results must be extrapolated with caution, one can safely conclude that compliance may be improved by simply selecting better locations for trail registers. In this study, relocating the registration station resulted in a 56 percent registration of the horse users, 88 percent of the overnight hikers, and 65 percent of the day hikers. These rates allow useful and reasonably reliable expansion of the data. Depending on the type of information managers are seeking, trail registers still constitute an effective means of gathering information about users and their use patterns.

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Four combinations of sign and location were studied on three trails in the Bob Marshall Wilderness, MT, to determine effect on visitor registration rates. Registration rates generally improved, and for some classes of visitor doubled, when the station was moved 1 to 3 miles up the trail from the trailhead. Sign message, though less influential than location, significantly raised registration rates for some visitors. Registration stations should be located where it is convenient for visitors to stop along the trail.

KEYWORDS: registration, compliance, trail registers

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Research Paper
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March 1985

Predicting Duff and Woody Fuel Consumed by Prescribed Fire in the Northern Rocky Mountains

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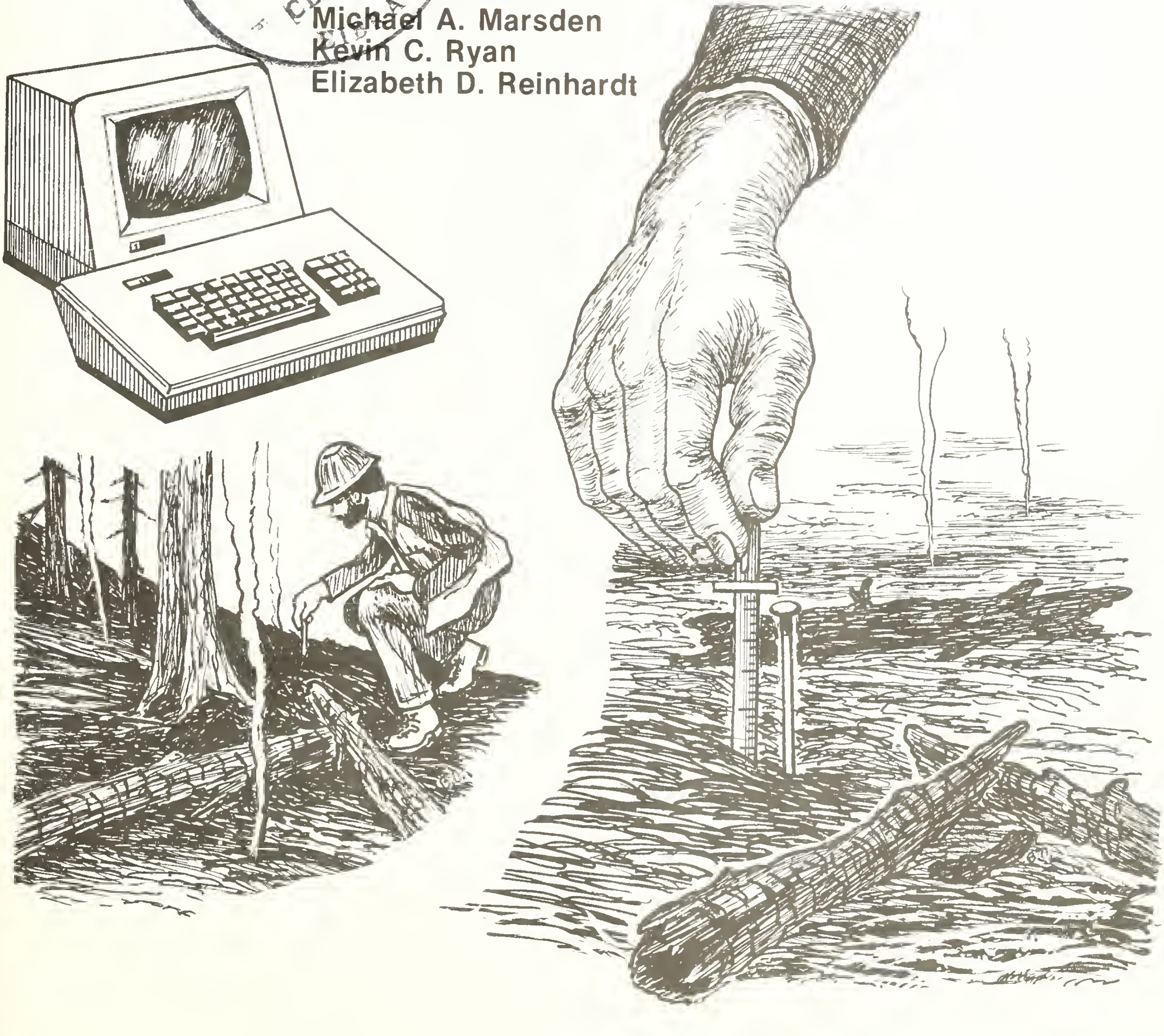

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JAMES K. BROWN received his bachelor's degree from the University of Minnesota in 1960, his master's from Yale University in 1961, and his Ph.D. from the University of Michigan in 1968, all in forestry. From 1961 to 1965, he did research on field measurement of fuel properties and fire-danger rating systems while with the Lake States Forest Experiment Station. In 1965, he transferred to the Northern Forest Fire Laboratory, Missoula, MT, where he conducted research on the physical properties, inventory, and prediction of fuels. Since 1979, he has been leader of a fire effects and use project in Missoula.

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RESEARCH SUMMARY

Relationships for predicting consumption of forest floor duff and downed, dead, woody fuel were determined to assist managers in planning prescribed fires. Data were analyzed from three previous prescribed fire studies in slash and nonslash fuels in cover types comprising a mixture of western larch, Douglas-fir, ponderosa pine, lodgepole pine, Engelmann spruce, subalpine fir, and grand fir. Duff depth reduction, percentage duff depth reduction, and percentage mineral soil are shown as regression functions of lower duff moisture content, entire duff moisture content, National Fire-Danger Rating System (NFDR) 1,000-hour moisture content, Canadian Adjusted Duff Moisture Code, preburn downed woody fuel loading, and preburn duff depth. Tests of the duff consumption relationships against other published data support their wide application.

Lower duff moisture content was the best predictor. Preburn downed woody fuel loading was of minor importance in the relationships. The NFDR 1,000-hour moisture predicted duff consumption with adequate precision for general guidance in developing fire prescriptions.

The NFDR 1,000-hour moisture was a better predictor of duff consumption and lower duff moisture than were two Canadian Duff Moisture Codes. The relationship between percentage mineral soil exposure and percentage duff reduction indicates that combustion in duff progresses both downward and laterally.

Consumption of downed woody fuel correlated strongly with preburn loadings. Percentage consumption, however, related weakly to all independent variables. Consumption differed substantially between slash (81 percent) and nonslash (46 percent). An evaluation of Sandberg and Ottmar's (1983) diameter reduction model based on large pieces of fresh slash underestimated by 35 percent the consumption of mostly rotten nonslash fuels, indicating the extent that consumption differs between sound and rotten material.

Predicting Duff and Woody Fuel Consumed by Prescribed Fire in the Northern Rocky Mountains

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INTRODUCTION

Predicting the consumption of forest floor duff is essential to skillful planning of prescribed fires. Duff includes both the fermentation and humus layers of the forest floor. Soil scientists call duff the O2 soil horizon. Duff lies below the litter and above mineral soil. Duff influences many facets of the forest ecosystem; thus broad ecological knowledge is needed to evaluate the effects of its combustion. Duff and associated downed woody fuel must often be removed to reduce fire hazard, prepare seedbeds, kill selected vegetation, and stimulate desired plants. In contrast, retention of duff and woody material may be needed to protect sites from sun and erosion, enhance microbial activity, and provide small animal habitat. Smoke from the burning of duff may adversely affect air quality. To successfully accomplish the sometimes complex objectives of prescribed fires, consumption of duff and woody fuel must be competently planned and executed.

This paper presents numerical relationships of known precision for predicting duff consumption. They were established by assembling and analyzing data from three previous prescribed fire investigations and then testing them against other published data. Fuel loadings by diameter classes that differed among the studies were converted to a common set of diameter classes. The purpose of assimilating data from several studies was to develop predictive models that could be easily used by practitioners and that would apply over a wide range of conditions.

Duff consumption is often expressed in three ways: depth reduction, percentage depth reduction, and percentage mineral soil exposed. Each expression is appropriate to evaluating certain prescribed fire objectives. Mineral soil exposure, for example, is commonly used to define site preparation needs. Depth of duff reduction relates to actual amount consumed and smoke production. Percentage duff reduction is useful for describing and setting objectives of prescribed fire to leave specified amounts of duff on site.

Consumption of duff is strongly influenced by moisture content. Van Wagner (1972) developed a model of duff consumption based on theoretical considerations of variation of flame emissivity with water content. Empirical coefficients for the model were derived from jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), and eastern white pine (*Pinus strobus*) stands in eastern Canada. Sandberg (1980) found that Van Wagner's models required modifications to provide good predictions for underburning in partially cut Douglas-fir stands in Washington and Oregon.

Sandberg's (1980) findings, and those by Artley and others (1978), Norum (1977), and Shearer (1975) in western Montana agreed well and suggested that duff burns independently of surface fuels below a duff moisture content of about 30 percent. In contrast, burning is meager above a moisture content of about 120 percent. Between these moisture limits, combustion of duff appears related to its moisture content and heat from surface fire. Other factors such as preburn duff depth and physical disturbances of duff may also influence the degree of consumption. Because prescribed burning is frequently done at duff moisture contents between 30 and 120 percent, the relationships for predicting consumption need to be better understood and quantified.

Some fire weather indices correlate reasonably well to duff consumption. For example, Van Wagner (1972) and Chrosciewicz (1978a,b) related duff consumption to the Duff Moisture Code of the Canadian Fire Weather System. Beaufait and others (1977) regressed duff consumption against upper duff moisture content and the Buildup Index from the old National Fire-Danger Rating System (USDA Forest Service 1964). Sandberg (1980) developed equations for predicting duff depth reduction and mineral soil exposure from the National Fire-Danger Rating System (NFDR) 1,000-hour moisture model (Deeming and others 1977). Although fire-danger rating indices relate only indirectly to duff moisture content, they are easily determined. Thus, relationships between fire-danger rating indices and duff consumption can be valuable for planning if they are adequately precise. Additional investigation is needed to confirm or modify Sandberg's findings with the widely used NFDR 1,000-hour moisture model.

Mineral soil exposure following fire can vary considerably. Efforts to predict exposure have sometimes been unsuccessful (Van Wagner 1972; Chrosciewicz 1978a,b). Norum's (1977) procedure for predicting mineral soil exposure, which assumes that duff burns off in uniform layers, was successful in a study of undisturbed fuels, but was unsuccessful when applied following partial cuttings (Sandberg 1980). Physical disturbance of the duff and a tendency for duff to burn laterally rather than downward may cause inconsistent results when using this method.

Martin and others (1979) concluded that fuels less than ¼-inch diameter are almost completely consumed by fire over a wide range of environmental conditions. Branchwood from ¼- to 3-inch diameter is largely consumed. Norum (1976) found that consumption of 0- to ¼-inch, ¼- to 1-inch, and 1- to 3-inch diameter woody fuels was strongly correlated to preburn loading of these fuels and moisture content. Other than this, little has been reported on predictive equations for consumption of small, downed, woody fuels (3-inch diameter and smaller).

Consumption of large woody fuels (larger than 3-inch diameter) depends primarily on their moisture content, degree of rot, and arrangement. Albini (1976) developed a theoretical model that predicts consumption of large fuels and time history of intensity. The model, which is largely untested, assumes a random distribution of pieces and depends on moisture content and planform overlap. In underburning of natural fuels, Norum (1976) found that moisture content and loading of smaller fuels were significant predictors of large fuel consumption. Sandberg and Ottmar (1983), in cable-yarded logging debris, observed that unit average consumption was not influenced by piece arrangement, species composition, or age of slash. They furnished equations for estimating large fuel consumption as a function of fuel moisture content.

By examining data from several sources, this study furnishes predictive equations over a wide range of preburn fuel conditions. Experimental fires in slash and nonslash fuels from several cover types and ignited in varying patterns are included in the analysis. A new technique is used to evaluate exposure of mineral soil. The predictive equations include one or two independent variables readily obtained by practitioners. Practical results are presented in a section on management applications and the details of analysis discussed in another section.

METHODS

Data from the following prescribed burn studies in western Montana and northern Idaho were assimilated and analyzed:

1. Beaufait and others (1977)—This study was conducted in clearcut logging slash created in old-growth forests when utilization standards were less stringent than today (fig. 1). This was perhaps the first study in

Figure 1.—A broadcast burn in clearcut logging slash at Miller Creek.

the Western United States to relate burn accomplishment to fuel quantity and moisture content quantitatively. Slashing and directional felling were used to maintain fuel continuity. No mechanical preparation was done within the study units. The study is referred to as Miller Creek-Newman Ridge (MN) in this paper.

2. Norum (1976)—This study occurred in an uncut mature stand dominated by Douglas-fir (fig. 2). It was prompted by the need for guides to assist in the planning of underburns to reduce fuels. This study is referred to as Lubrecht (L). Data were analyzed as spring (Ls) and fall (Lf) sets.

3. Baaken and Neuenschwander (1981)—This study was conducted in seral ponderosa pine stands that had been selectively harvested followed by mechanical piling in 1978. Logging disturbance to the surface fuel and soil varied substantially among units. The purpose of the study was to relate preburn conditions and fire behavior to accomplishment of silvicultural objectives. This study site is referred to as northern Idaho (NI).

Study sites are described further in table 1.

Analysis of duff was emphasized in this report because the data were sampled with respectable reliability in all studies and promised to offer relationships useful to planning of prescribed fires. Small woody fuel, which includes material less than 3 inches in diameter, was also adequately sampled in all studies and was used as an independent variable to predict duff consumption. Sampling of large fuels, however, was adequate only for Lubrecht and northern Idaho. Our analysis was directed at determining relationships not explored in the other studies and examining relationships from combined data.

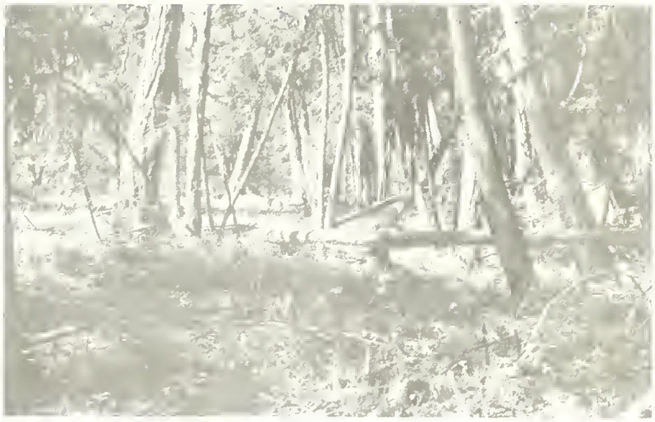

Figure 2.—Fuel and stand conditions prior to underburning a unit at Lubrecht.

Table 1.—Description of study sites

Site	Miller – Newman	Lubrecht	Northern Idaho
Location	Flathead and Lolo National Forests, MT	University of Montana Lubrecht Experimental Forest, MT	Coeur d'Alene Indian Reservation, ID
Cover type	Western larch/ Douglas-fir primarily; other species were grand fir, ponderosa pine, lodgepole pine, subalpine fir, Engelmann spruce, and western white pine	Western larch/Douglas – fir	Ponderosa pine; sparse Douglas – fir understory
Plot size, acres	2-½	⅓	½ to 2½
Slope, percent	9 to 76	20 to 50	0 to 30
Elevation, feet	4,200 to 5,400	4,790	2,590 to 2,890
Burn dates	May, June, July, Aug., Sept., Oct., 1967 – 69	May, June, July, Sept., Oct., 1973	Sept., Oct., 1978
Dead 1 – hour timelag fuel moisture, percent	6 to 21	9 to 35	9 to 21
Ignition pattern	Single headfire	Strip headfire	Strip headfire, single headfire, backfire

Small fuel loadings ranged from 0.1 to 36 tons/acre (0.2 to 81 t/ha). Duff depths ranged from 0.1 to 4.3 inches (0.3 to 11 cm). Ranges of all variables and their abbreviations are shown in table 2.

To facilitate comparison of data for small, woody fuels, loadings by diameter class for Miller Creek and Newman Ridge were converted to the conventional 0- to ¼-inch (0- to 0.6-cm), ¼- to 1-inch (0.6- to 2.5-cm), and 1- to 3-inch (2.5- to 7.6-cm) classes, appendix I. These correspond to the NFDR 1-, 10-, and 100-hour average moisture timelag size classes (Fosberg 1970) adhered to in the other studies.

No attempt was made to model fuel reduction separately for 0- to ¼-inch, ¼- to 1-inch, and 1- to 3-inch classes. Instead, diameter classes were grouped. Woody fuels 0 to 1 inch and 0 to 3 inches were analyzed as separate variables. Fuel consumption for 0- to ¼-inch, ¼- to 1-inch, and 1- to 3-inch classes was not evaluated because incomplete combustion may cause woody pieces to change diameter classes. This introduces error in determining consumption for any single class. The 0- to 1-inch and 0- to 3-inch classes were considered large enough to furnish reasonably accurate estimates of consumption by minimizing these errors.

Table 2.—Ranges of variables studied

		Study Location[1]			
Variable	Abbreviation	MN	L_f	L_s	NI
Duff depth reduction, percent	DR%	1 to 100	23 to 73	14 to 35	0 to 56
Mineral soil exposure, percent	M%	0 to 93	1 to 51	0 to 16	—
Duff depth reduction, inches	DR	0 to 2.4	0.6 to 3.0	0.5 to 1.1	0 to 1.1
Preburn duff depth, inches	DPRE	0.1 to 3.2	1.7 to 4.3	2.0 to 3.3	0.6 to 2.6
Lower duff moisture content, percent	LDM	40 to 219	23 to 103	40 to 145	—
Entire duff moisture content, percent	EDM	30 to 221	16 to 102	28 to 106	9 to 46
NFDR 1,000 – hour timelag moisture content, percent	TH	7 to 25	11 to 15	13 to 18	17 to 20
Canadian Adjusted Duff Moisture Code	ADMC	13 to 249	91 to 162	26 to 86	33 to 119
Preburn 0 – 3-inch woody fuel load, tons/acre	WT3	12.84 to 35.80	1.44 to 7.68	1.33 to 4.27	0.10 to 11.06
0 – 3-inch woody fuel consumed, tons/acre	CWT3	8.07 to 29.88	0.23 to 6.41	0 to 2.13	0 to 10.40
Preburn 0 – 1-inch woody fuel load, tons/acre	WT1	3.44 to 14.80	0.55 to 2.13	0.64 to 1.13	0.03 to 10.27
Preburn 3+-inch woody fuel load, tons/acre	WTLG	—	4.84 to 47.96	9.55 to 46.92	0 to 37.44
3+ woody fuel consumed, tons/acre	CWTLG	—	0 to 41.10	3.16 to 39.43	0 to 16.97
Reaction intensity, Btu/min/ft²	RI	1,321 to 5,881	46 to 2,677	431 to 1,872	826 to 5,302

[1] MN = Miller – Newman; L_f = Lubrecht, fall; L_s = Lubrecht, spring; NI = northern Idaho.

A strategy for analysis involved these steps:

1. Examine scattergrams to identify outliers and possible relationships. A few implausible outliers were discarded.
2. Perform regression analysis on candidate relationships for separate and pooled data sets. Criteria followed in determining functional relationships were to keep functional forms as simple as possible, keep the number of variables to a minimum, and involve only variables that have a physical reason for existence and can be obtained by managers.
3. Select good-fitting relationships: regressions that have low standard errors of estimate and predict well for other data sets. Goodness-of-fit of given functions to their own and to other data sets was evaluated using the average difference between observed and predicted values to indicate bias (table 3). The root mean square of differences between observed and predicted values provided estimates of precision. Standard errors of the estimate from regression analysis were numerically close to the root mean square of differences. They differed only in that the denominator for the standard error was degrees of freedom rather than number of observations. Standard errors and r^2 values for several segmented regressions were based on data for both segments.
4. Pick the best fitting relationships and test them against other fuel consumption data and relationships in the literature. "Best" equations were those having the smallest standard errors and most consistent predictions.

Preliminary Duff Analysis

Determination of mineral soil exposure.—Mineral soil exposure was not observed directly on the study sites. Instead, it was calculated from preburn and postburn duff depths measured at duff spikes (fig. 3). Mineral soil was considered exposed when 0.4 inch (1.0 cm) or less of unburned organic material was left after a fire. This criterion of mineral soil was chosen because postfire duff less than 0.5 inch (1.3 cm) in depth can be considered mineral soil for germinating seedlings (DeByle 1981; Shearer 1983). Germinating seedlings can penetrate through 0.5 inch of duff to become established in mineral soil. Also, additional duff reduction due to physical deterioration and decomposition seems to occur during the year or so following fire. This reduces residual duff even further beyond its immediate postfire quantity. A third reason for the 0.4-inch (1.0-cm) residual duff criterion is that residual duff depths cannot be measured very accurately until more than about 0.2 inch (0.5 cm) of duff is present. Scattergrams of percentage mineral soil versus median residual duff depth, using 0.2 inch and 0.4 inch as criteria for mineral soil showed less scatter for the 0.4-inch criterion. Thus, a 0.4-inch residual depth appeared large enough to measure accurately and small enough to qualify as a mineral soil seedbed.

Minimum duff depth.—Examination of scattergrams indicated that at preburn duff depths of less than about 0.8 inch (2 cm), the relationships between duff consumption and the independent variables became erratic. For

Table 3.—Statistics on precision and bias for duff reduction and mineral soil exposure equations shown in the text

Equation	Data source[1]	N	r^2	se	Average (O – P)[2]				Root mean square (O – P)			
					MN	L_f	L_s	NI	MN	L_f	L_s	NI
Duff Depth Reduction, Inch												
1	MN, L_f	71	0.76	0.31	0	0.03	−0.67	−1.26	0.30	0.38	0.74	—
2	MN	60	.66	.34	0	.34	−.32	−1.43	.34	.70	.50	—
3	MN, L_f	71	.72	.33	−.02	.14	−.81	−.89	.32	.39	.86	.92
4	MN	60	.63	.36	0	.47	−.41	−1.10	.35	.76	.54	1.14
5	MN, L_f	71	.58	.41	−.04	.25	−.40	−.45	.35	.61	.46	.52
6	MN, L_f, NI	119	.75	.31	.06	.08	−.62	−.06	.36	.37	.68	.20
7	MN, L_f	71	.48	.46	−.05	.27	−.15	−.59	.40	.67	.27	.65
Duff Depth Reduction, Percent												
8	MN, L_f	71	0.71	14.1	.6	−3.6	−25.1	—	14.4	11.5	28.5	—
9	MN, L_f	71	.74	13.5	.6	−2.6	−21.6	—	13.6	11.6	27.8	—
10	MN, L_f	71	.69	14.7	−.3	1.6	−30.4	−49.4	14.9	11.7	33.1	51.3
11	MN, L	79	.66	15.2	.7	6.6	−14.1	—	14.6	12.3	19.6	—
12	L_f	11	.58	10.5	−54.7	−.1	−18.1	—	59.4	8.9	22.2	—
13	MN, L_f	71	.55	17.6	.6	−3.2	−25.5	−15.1	18.2	11.7	26.9	19.3
14	MN, L_f, NI	119	.58	16.4	1.9	4.9	−16.0	−3.6	19.3	11.9	18.5	12.4
15	MN, L_f	71	.49	18.9	.5	−2.6	−15.3	−20.5	19.6	12.2	17.2	23.4
16	MN, L_f	66	.85	9.9	−2.8	13.8	2.4	—	8.0	15.7	5.4	—
Mineral Soil Exposure, Percent												
17	MN, L_f	72	0.58	16.1	2.6	−14.3	−23.5	—	15.7	17.0	28.3	—
18	L_f	11	.53	10.0	21.6	0	−10.0	—	27.3	9.1	17.4	—
19	MN, L_f	72	.56	16.4	1.7	−8.2	−30.3	—	16.5	14.6	33.5	—
20	MN, L	80	.55	16.7	1.8	−1.4	−12.2	—	17.3	9.2	16.8	—
21	MN	61	.40	20.3	0	−18.3	−31.1	—	20.0	21.3	32.2	—
22	L_f	11	.36	11.7	22.6	0	−10.6	—	30.9	10.6	14.4	—
23	MN, L_f	66	.85	9.6	2.7	−13.4	−5.9	—	7.9	15.2	7.5	—

[1] L = all Lubrecht data; L_f = Lubrecht fall; L_s = Lubrecht spring.

[2] O = observed average values from burned units; P = predicted values.

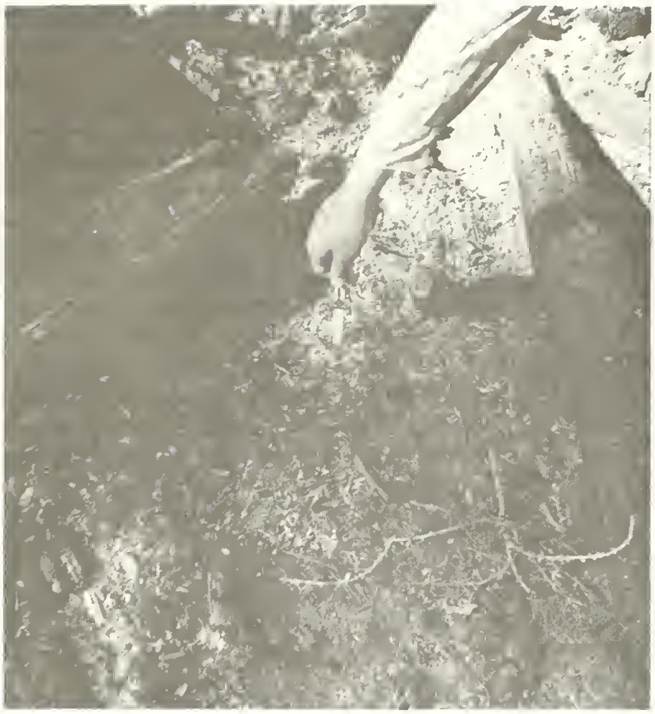

Figure 3.—Measurement of duff reduction along a spike. The head of the spike was flush with the top of the duff before the fire.

example, sometimes plots with very dry duff showed almost total consumption and sometimes very limited consumption. Variability in consumption was more plausible for duff greater than 0.6 to 0.8 inch (1.5 to 2 cm) in depth.

In a current study of duff combustion, Frandsen (1983) similarly observed that sustained burnout of duff ceases at an average depth of 0.6 inch (1.5 cm). Frandsen (1983) also found that such shallow duff tended to have more incorporated mineral matter, which may retard combustion. Because of the erratic consumption of shallow duff layers, preburn duff depth observations less than 0.6 inch (1.5 cm) were eliminated from our analyses.

Possible bias in MN data.—Beaufait and others (1977) reported that a bias due to dependence between fuel loadings and fuel moisture content developed at Miller Creek. Plots having heavy downed woody loadings were burned at higher fuel moistures because of a tendency to prescribe-burn the most flammable plots under relatively safe fire-weather conditions.

Correlation analysis and scattergrams suggest that the bias has more influence on downed woody fuel consumption than on duff consumption. Plots of duff depth over NFDR 1,000-hour moisture content show no correlation ($r = 0.026$). Duff depth and lower duff moisture were weakly correlated ($r = 0.17$). Duff depth and upper duff moisture content, which we did not include as a variable, were correlated ($r = 0.37$). Regressions using NFDR 1,000-hour moisture content and 0- to 3-inch woody fuel loading as dummy variables were attempted to overcome possible bias difficulties. This attempt, however, failed to improve precision or show consistent positive correlations between duff consumption and 0- to 3-inch woody fuel loading.

In analysis of small woody fuels, 0- to ¼-inch and ¼- to 1-inch diameter loadings were positively correlated with 1- and 10-hour timelag moisture contents. However, NFDR 1,000-hour moisture content and 1- to 3-inch woody fuel loadings were not correlated. The extent of possible bias in duff and small woody fuel consumption remains vague, but was probably inconsequential in duff.

Spring fires.—Fires occurring during May and June were considered spring burns. Eight Miller-Newman spring fires were recorded. Scattergrams indicated that Miller-Newman spring and fall fires were from a common population. Nine Lubrecht spring fires were recorded. Our scattergrams agreed with Norum's (1976) previous analysis and indicated that spring and fall fires were from different populations. The Lubrecht spring fires happened during a particularly dry spring following a winter of low snowfall. Because these fires burned during unusual spring weather and indicated a different pattern of fuel consumption than the fall fires, we (like Norum) analyzed the data as separate sets. Analyses including Lubrecht spring fires usually showed reduced precision compared to analyses not including spring fires. In a few cases, however, inclusion of these fires with other data sets improved precision.

Transformation of data.—Nonlinear relationships existed among some variables. To improve linearity, reciprocal and logarithmic transformations of most variables were tried in correlation and regression analysis. Transformations improved some correlations, but the improvements were generally small and not consistent among the data sets. Correlation coefficients between transformed and untransformed variables are displayed in appendix II. Both NFDR 100-hour and 1,000-hour timelag moisture contents were analyzed as independent variables because the moisture timelag of duff may be between the two. They were positively correlated as expected. In regression analysis, the 1,000-hour timelag moisture related more precisely with duff consumption; thus, equations having the 100-hour were not reported.

Lower and upper duff moisture.—Moisture contents were measured for the lower half and upper half of duff at Miller-Newman and Lubrecht, and for the entire duff profile in northern Idaho. An average moisture content (EDM) for the entire duff profile at Miller-Newman and Lubrecht was calculated as the mean moisture content for the lower half and upper half of the duff. Moisture contents for the lower and upper duff layers were positively correlated. Moisture for the lower layer was more highly correlated with dependent variables than was true for the upper layer. In regression analysis, upper duff moisture failed to explain significant variation beyond that explained by lower duff moisture. Thus, the results reported are based on moisture for the lower duff layer and the entire duff profile.

MANAGEMENT APPLICATIONS

This section contains the best relationships for predicting fuel consumption to help in planning prescribed fires.

They should apply to a wide range of fuels and cover types. The duff consumption relationships are the most useful because they are reasonably precise and relate to many important fire effects.

The first step in planning is to clearly define the objectives of the fire apart from the purpose for prescribing it. The objectives should specify what the fire itself is to accomplish immediately. These fire objectives basically involve specifying how much organic material should be consumed and what vegetation should be killed or left alive. Constraints on allowing a fire to burn must also be clearly defined. Constraints obviously include control of the fire and may also involve needs to retain some duff and large downed woody material on the burned sites. Once the desired removal of duff and woody material is specified, fuel moisture contents expected to achieve it can be determined from the relationships in this report.

Determining a fire prescription to result in specified amounts of fuel consumption can be viewed as a three-step process:

1. Decide how much fuel should be left on the ground after the fire.
2. Determine the amount of fuel that should be removed.
3. Determine a range in fuel moisture contents for achieving the specified fuel removal.

Steps 1 and 2 require consideration of many factors, including needs for seedbed preparation, fuel hazard reduction, protection of sites to resist erosion, and provision for maintaining desirable nitrogen levels. Needs for duff removal and duff retention may conflict and may require either a compromise on objectives and constraints or the selection of another alternative. The ranges in conditions tabulated below are suitable for application of the predictive relationships reported here.

Conditions	Range
Average duff depth, inches	0.5 to 4.5
Average lower duff moisture, pct	30% and greater
Average entire duff moisture, pct	20% and greater
Forest overstory species	Best suited to midelevation forests dominated by western larch, Douglas-fir, grand fir, ponderosa pine, lodgepole pine, Engelmann spruce, subalpine fir, and western white pine
Woody surface fuels	Slash and nonslash
Ignition method	Strip head fires, possibly back fires; area ignition untested

Application beyond these conditions could result in large errors. Most of the duff consumption relationships were derived from variable data. Thus, wide limits on reliability of predictions should be kept in mind when predicting duff consumption. Deviations from predicted values are probably influenced primarily by degree of soil disturbance, variation in duff depth and moisture content, and method of ignition. Generally, less consumption than predicted can be expected where logging disturbance is considerable. In contrast, more consumption can be expected where the firing method results in ignition of all surface fuels. The most accurate predictions can be expected where the terrain is uniform and the stands have developed under closed or nearly closed canopies. In prescribed burn units where stand history and microclimate are varied, the area can be stratified and more than one prediction made.

Duff Depth Reduction

The depth of duff consumed may be used to estimate the actual change in organic matter and nutrients on a site. It also relates to the amount of smoke produced by burning (Ottmar 1984). If seed stored in the forest floor and the rooting depth of plants are known, the depth of duff consumed can be used to evaluate a fire's impact on postburn succession.

Duff depth reduction can be predicted from lower duff moisture content in figure 4. Knowledge of preburn duff depth (DPRE), from either on-site measurements or observations of similar sites, should be utilized in figure 4 for best accuracy. If preburn depth is not known, assume it is 2 inches (5 cm). This value is close to the average preburn duff depth of this study. It is slightly greater than the average duff depth found over a broad range of cover types in the Northern Rocky Mountains (Brown and See 1981).

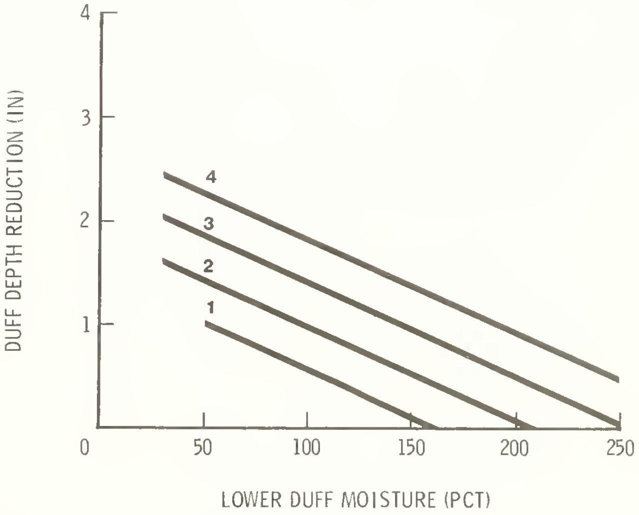

Figure 4.—Duff depth reduction versus lower duff moisture content by preburn duff depths (equation 1). One standard error about predictions is 0.3 inch (0.8 cm). Numbers along curves identify preburn duff depths.

Moisture content for the entire duff profile can be substituted for lower duff moisture in figure 4. This will result in duff reduction being overpredicted by an average 0.15 inches (0.4 cm), an inconsequential amount for practical purposes. Lower duff moisture is recommended for planning duff consumption in prescribed fires because it relates more closely to duff consumption over a wider range of conditions than entire duff moisture. Sometimes, however, it is not practical to separate duff moisture samples into upper and lower strata, particularly when duff depths are 1 inch or less. In such cases or for personal preference, the entire duff moisture can be applied satisfactorily to predicting duff consumption.

The NFDR 1,000-hour moisture content can be used to predict duff depth reduction in figure 5. If duff depth is unknown, assume a depth of 2 inches (5 cm). The recommended use of figure 5 is for long-range planning and for judging when duff moisture contents are approaching the prescribed range. Users should be aware of two potential sources of error. First, the NFDR 1,000-hour moisture content is intended to apply to 3- to 6-inch (7.6- to 15-cm) logs (Deeming and others 1977), not duff. Log moisture content is dependent primarily on the duration of rain, whereas the duff moisture is more strongly determined by the amount. The second potential source of error is in extrapolating from a weather station to a burn site. If precipitation differs between these locations, predictions of duff consumption will be in error in proportion to the difference in precipitation.

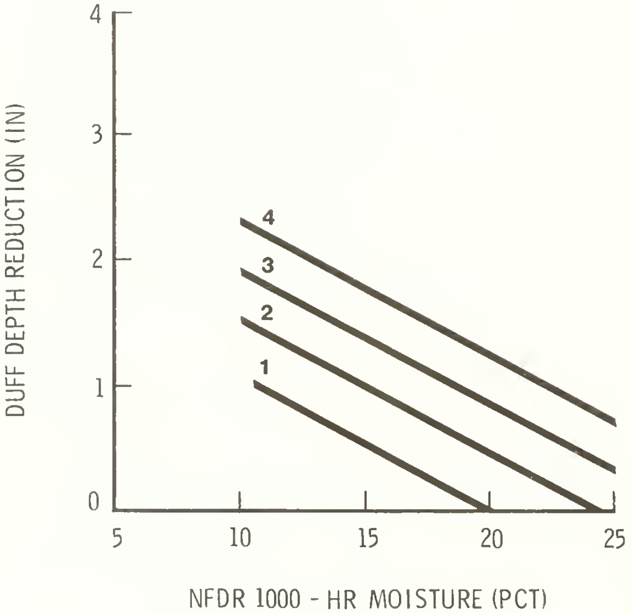

Figure 5.—Duff depth reduction versus NFDR 1,000-hour moisture by preburn duff depths (equation 6). One standard error about predictions is 0.3 inch (0.8 cm). Numbers along curves identify preburn duff depths.

Percentage Duff Depth Reduction

Percentage duff depth reduction is useful because it describes duff consumption independent of duff depth. It is easily understood by others as a prescribed fire objective and is especially suitable for describing the amount of duff to be left unburned for needs such as site protection. Percentage duff reduction can be predicted from lower duff moisture, using figure 6. It can also be predicted by substituting entire duff moisture for lower duff moisture in figure 6 and adjusting percentage duff reduction as follows:

Entire duff moisture	**Duff depth reduction**
Percent	*Percent*
Less than 80	Subtract 10
80 to 120	Subtract 5
Greater than 120	No change

When duff moisture content exceeds 150 percent for either the entire duff profile or the lower layer, duff consumption will remain about 10 to 15 percent. This assumes that a spreading fire is possible. At low duff moistures, 80 to 100 percent consumption can be expected.

The relationship between percentage duff reduction and NFDR 1,000-hour moisture is imprecise and best used as an indicator of when duff moisture may be within prescription. Generally, when NFDR 1,000-hour moisture falls below 25 percent, percentage duff consumption begins increasing. Duff moisture contents are apt to be within prescription when NFDR 1,000-hour moisture is between 10 and 25 percent.

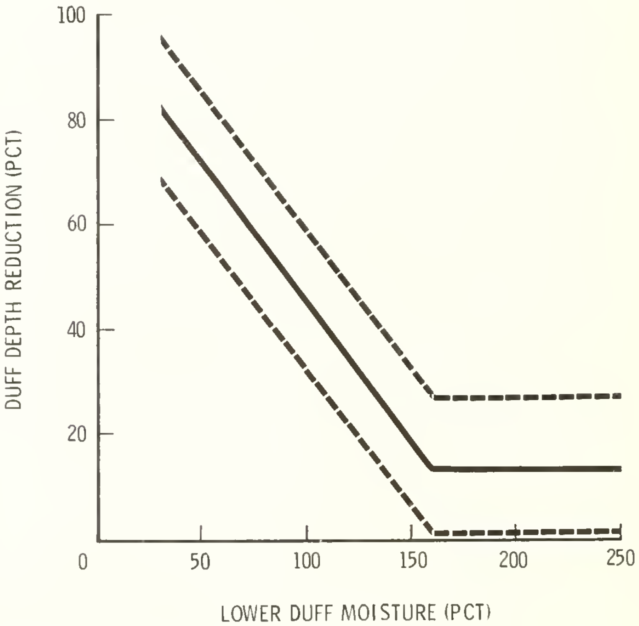

Figure 6.—Percentage duff reduction versus lower duff moisture content (equation 9). The dashed lines are one standard error prediction bands.

The relationship between percentage duff reduction and percentage mineral soil exposure in figure 7 shows how much duff must be removed to expose varying amounts of mineral soil. It can be used, for example, to evaluate whether objectives to create mineral seedbeds are compatible with objectives to retain duff for site protection and as a source of nitrogen.

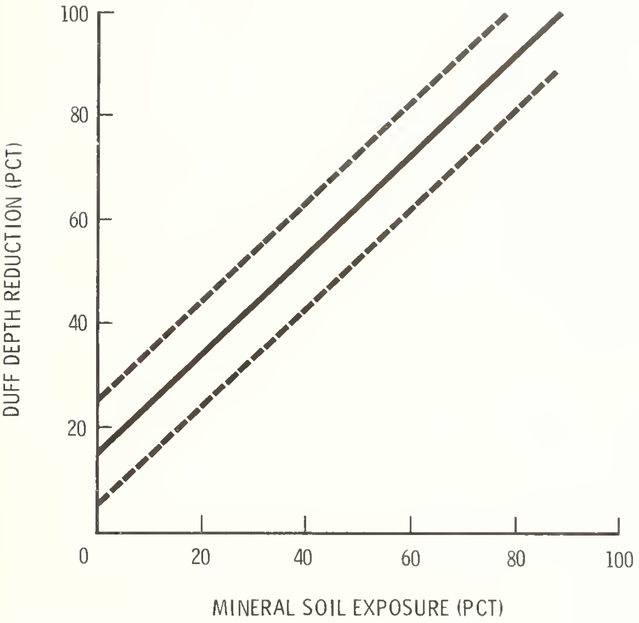

Figure 7.—Percentage duff reduction versus percentage mineral soil exposure (equation 16). The dashed lines are one standard error prediction bands. As a rule of thumb, percentage duff reduction equals percentage mineral soil exposure plus 15 percent.

Percentage Mineral Soil Exposure

The predicting of mineral soil exposure is most commonly used for planning use of fire to prepare seedbeds. Percentage mineral soil can be predicted using figure 8, which offers separate curves for light and moderate to heavy downed woody surface fuels. Light fuels are considered as less than 10 tons per acre (22.4 t/ha) of 0- to 3-inch woody fuel. This includes slash from light cuttings and most nonslash fuels. Moderate to heavy fuels are considered as 10 tons per acre and greater of 0- to 3-inch downed woody fuel typically from partial cutting and clearcutting activities. Moisture content for the entire duff profile can be substituted for moisture of the lower duff layer when estimating percentage mineral soil for the heavier fuel loading curve in figure 8, using the following adjustments:

Entire duff moisture	**Mineral soil exposure**
Percent	*Percent*
Less than 40	Subtract 5
40 to 90	Subtract 10
90 to 120	Subtract 5
Greater than 120	No change

The relationship between percentage mineral soil exposure and NFDR 1,000-hour moisture was imprecise as it was for percentage duff reduction. The following guidelines indicate when duff moistures are within prescription:

NFDR 1,000-hour moisture	**Mineral soil exposure**
Percent	*Percent*
Greater than 25	Less than 10
10 to 25	10 to 50
Less than 10	Greater than 50

Small Woody Fuels

Generally, percentage consumption of small woody fuels is consistently high when loadings of this material exceed 10 tons/acre (22.4 t/ha). Consumption is variable but considerably less at lighter loadings. The following tabulation offers as much precision for predicting percentage small woody fuel consumption as is reliable and practical:

Small woody fuel loading	**Consumption**
Tons/acre	*Percent*
Less than 10	Less than 50
10 and greater	70 to 90

The influence of small woody fuel moisture content on percentage consumption appears minor once fire spread is sustained. When quantities of small woody fuels are light, however, percentage consumed depends partly on fuel continuity. Spread of fire is disrupted in sparsely distributed fuels, thus creating unburned fuel patches. In prescribed burning, however, the method of ignition

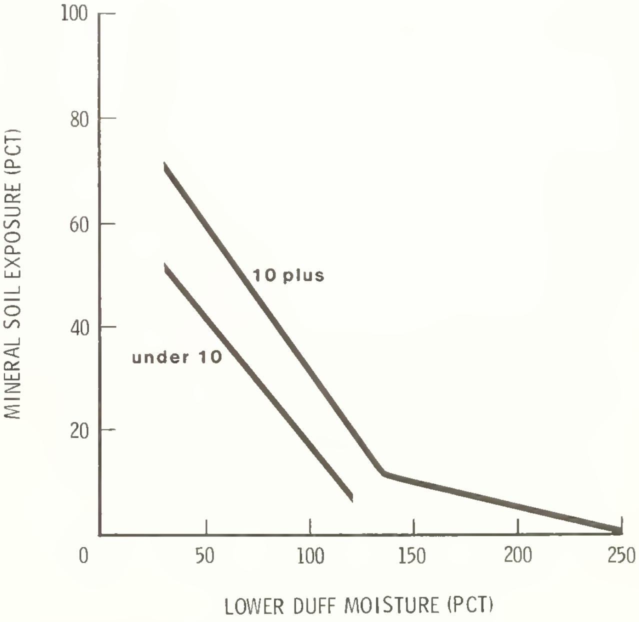

Figure 8.—Percentage mineral soil exposure versus lower duff moisture for 0- to 3-inch downed woody surface fuel loadings of less than 10 tons/acre (equation 18) and 10 tons/acre and greater (equation 17). Standard errors for predictions are 10 and 16 percent, respectively.

can partially overcome the breakdown in fire spread to increase fuel consumption. Because of this, prediction of percentage consumption in light quantities of small woody fuels may remain imprecise.

Large Woody Fuels

Although fuel moisture is clearly the primary influence on large woody fuel consumption, quantified guidance for predicting consumption is meager, especially in the Northern Rocky Mountains. Until new information is published, we suggest consulting the following sources of information for guidance:

Recent harvesting slash (Sandberg and Ottmar 1983).—The approximate relationship between large fuel consumption and NFDR 1,000-hour moisture (based on midpoint diameters of size classes) is:

NFDR 1,000-hour moisture	Consumption	
	3 to 6 inches	6 to 9 inches
Percent	*Percent*	*Percent*
10	100	80
15	95	70
20	80	55
25	65	40
30	40	25

Nonslash fuel underburns (Norum 1976).—The following generality is based on the finding that large woody fuel consumption and duff reduction are correlated:

Lower duff moisture	Consumption
Percent	*Percent*
0 to 40	50 to 100
40 to 100	10 to 50
100 +	Less than 20

ANALYSIS AND DISCUSSION

Results of analyses are discussed separately under duff depth reduction, percentage duff depth reduction, and percentage mineral soil exposure. Statistics on precision and bias of the equations in this section are shown in table 3. In addition, numbers of burn units (N), coefficients of determination (r^2), and standard errors of regression (se) are shown below each equation. Metric units for all equations are shown in appendix III. When addition of a second independent variable resulted in a significant and meaningful improvement in precision, equations having one and two independent variables are presented.

Duff Depth Reduction (DR)

The best equations having lower duff moisture (LDM) as an independent variable were:

$$DR = 1.028 - 0.0089\ LDM + 0.417\ DPRE \qquad (1)$$
$$(N = 71,\ r^2 = 0.76,\ se = 0.31)$$
$$DR = 1.801 - 0.0079\ LDM \qquad (2)$$
$$(N = 60,\ r^2 = 0.66,\ se = 0.34)$$

The best equations having entire duff moisture (EDM) as an independent variable were:

$$DR = 0.8811 - 0.0096\ EDM + 0.439\ DPRE \qquad (3)$$
$$(N = 71,\ r^2 = 0.72,\ se = 0.33)$$
$$DR = 1.682 - 0.0085\ EDM \qquad (4)$$
$$(N = 60,\ r^2 = 0.63,\ se = 0.36)$$

Where duff layers are thin, such as in northern Idaho, it is impractical to separate upper and lower duff for moisture sampling. In these situations entire duff moistures are the most appropriate for characterizing duff. Where duff depth exceeds about 1 inch (2.5 cm), however, there is a tradeoff between simplicity and precision. Collecting lower duff samples by separating the lower one-half of the duff from the duff and litter above should produce the most precise prediction. In contrast, collecting samples from the entire duff layer avoids the task of separation but may result in a less precise estimate of duff consumption.

Using both duff moisture and preburn duff depth (DPRE) as independent variables produces regression equations that are more precise than those with duff moisture as a single independent variable (compare equations 1 and 2 and equations 3 and 4). For preburn duff depths less than 2 inches and lower duff moistures less than about 50 percent, depth reduced approaches the preburn depth (fig. 4). Examination of plotted data showed that when duff is dry, preburn duff depth and duff depth reduced are highly correlated because dry duff generally burns out well. When damp, such as above about 100 percent moisture content, the correlation is poor; hence, preburn duff depth alone is not a reliable predictor.

Predicted by fire weather indices.—The best equations having NFDR 1,000-hour moisture (TH) as an independent variable were:

$$DR = 2.698 - 0.1035\ TH \qquad (5)$$
$$(N = 71,\ r^2 = 0.58,\ se = 0.41)$$
$$DR = 1.773 - 0.1051\ TH + 0.399\ DPRE \qquad (6)$$
$$(N = 119,\ r^2 = 0.75,\ se = 0.31)$$

Although duff probably varies in its time response for drying, the NFDR 1,000-hour moisture correlated reasonably well with duff consumption over the range of depths studied. For regression with NFDR 1,000-hour moisture alone, equation 5 provided the best fit to all data of any combination of data sets. Addition of preburn duff depth to regression equation 6, improved precision for all data set combinations. Equation 6 is the most robust for application because it is based on the largest range in data. Bias averaged less than 0.08 inches (2 mm) except for Lubrecht spring (table 3). The range in NFDR 1,000-hour moisture (7 to 25 percent) for equations 5 and 6 was reasonably large but somewhat limited on the moist end of the scale for extrapolation.

Lower duff moisture content predicted duff consumption with only slightly more precision and less bias than NFDR 1,000-hour moisture, which was surprising because NFDR 1,000-hour moisture is only an indicator of moisture content. The relationship between lower duff moisture and NFDR 1,000-hour moisture (fig. 9) illustrates the possible limitations of relating duff consumption to fire-danger moisture models due to the imprecise association between moisture models and duff moisture content. Regression of duff consumption on the Canadian Adjusted Duff Moisture Code (Van Wagner 1974), equation 7, was slightly less precise than on NFDR 1,000-hour moisture:

$$DR = 0.4094 + 0.0070\ ADMC \qquad (7)$$
$$(N = 71,\ r^2 = 0.48,\ se = 0.46)$$

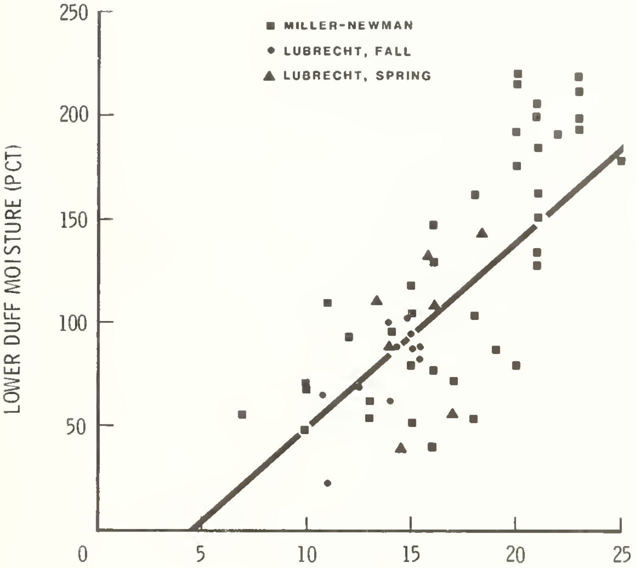

Figure 9.—Lower duff moisture content versus the NFDR 1,000-hour moisture content.

Percentage Duff Depth Reduction (DR%)

Predicted by duff moisture.—Prior work by Shearer (1975) and Norum (1977) at Miller Creek and Lubrecht showed similar relationships between percentage duff reduction and lower duff moisture content. Statistics on precision, however, were not furnished. We reexamined this relationship primarily to estimate sampling precision. Scattergrams indicated a curvilinear relationship between percentage duff reduction and lower duff moisture and that the Miller-Newman and Lubrecht fall data could be pooled (fig. 10). The best linear regression fit was:

$$DR\% = 87.8 - 0.390\ LDM \qquad (8)$$
$$(N = 71,\ r^2 = 0.71,\ se = 14.1)$$

High variability in duff consumption at the lower duff moistures made the data difficult to fit. Reciprocal and logarithmic transformations failed to improve fit. Likewise, analysis using MATCHACURVE (Jensen and Homeyer 1970) failed to improve fit over equation 8. Finally, the following segmented regression improved precision slightly and fit Lubrecht fall data with slightly less bias than equation 8 (table 3, fig. 3):

$$DR\% = 97.1 - 0.519\ LDM,\ LDM \leq 160 \text{ percent} \qquad (9)$$
$$13.6,\ LDM > 160 \text{ percent}$$
$$(N = 71,\ r^2 = 0.74,\ se = 13.5)$$

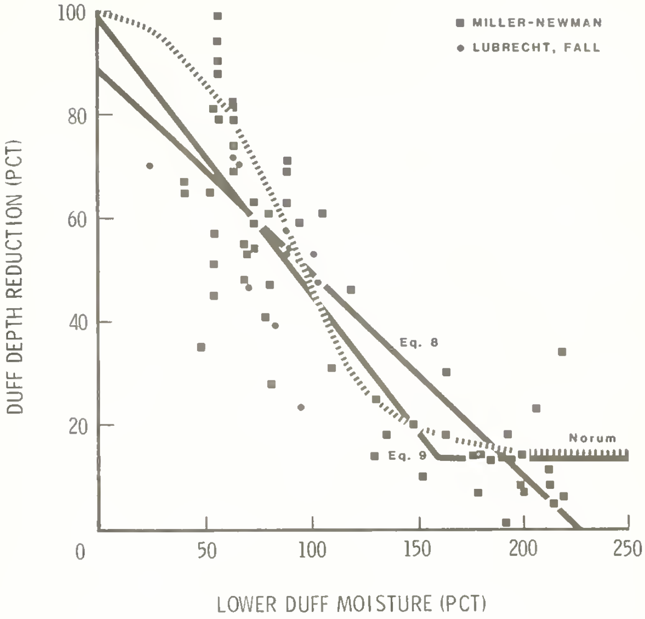

Figure 10.—Percentage duff depth reduction versus lower duff moisture content. Equations 8 and 9 and Norum's (1977) curves are graphed.

The segmented regression is appealing because the data form a knee where consumption levels off, and the regression avoids unreasonable solutions when applied at high moisture contents.

The best equation having entire duff moisture as an independent variable was:

$$DR\% = 83.7 - 0.426\ EDM \qquad (10)$$
$$(N = 71,\ r^2 = 0.69,\ se = 14.7)$$

Influence of surface fuel.—Duration of surface fire should be better than surface fuel consumption as a predictor of duff consumption, because preheating and drying of duff should relate more closely to duration of free-burning fire than to intensity or other fire characteristics. In a practical sense this may be a minor point because woody fuel consumption and duration are probably positively correlated. We were unable to estimate surface fire duration from our data but did examine the significance of 0- to 1-inch and 0- to 3-inch woody fuel preburn loadings and consumption in regression.

Preburn loadings of the 0- to 3-inch woody fuel (WT3) and the consumed loadings were highly correlated. In the first screening using regression analysis, the preburn loading performed as well as consumed loading in explaining variation. Thus, consumed loading was omitted from later regression analyses because in practice it is more difficult to determine than preburn loading. Generally, 0- to 3-inch woody fuel was a better predictor than 0- to 1-inch woody fuel.

The following equation for the Miller-Newman and Lubrecht pooled data shows an influence of surface fuels that is intermediate to equations for Miller-Newman and Lubrecht separately:

$$DR\% = 75.8 - 0.397\ LDM + 0.656\ WT3 \qquad (11)$$
$$(N = 79,\ r^2 = 0.66,\ se = 15.2)$$

In multiple regression analysis, 0- to 3-inch woody fuel was nonsignificant when entered after lower duff moisture for the Miller-Newman data, but was highly significant in the following equation for the Lubrecht data:

$$DR\% = 70.2 - 0.384\ LDM + 3.72\ WT3 \qquad (12)$$
$$(N = 11,\ r^2 = 0.58,\ se = 10.5)$$

Miller-Newman data confirmed Sandberg's (1980) findings that once lower duff moisture was known, woody fuel loading in slash had an inconsequential influence on duff consumption. Perhaps downed woody slash fuel is less influential on duff consumption because much of it is suspended above the duff. In naturally occurring fuels, such as at Lubrecht, much of the woody fuel lies on the litter and duff. Heat transfer between duff and woody fuel would be more efficient and highly correlated. In this situation, burnout of woody fuel would probably support burnout of the duff.

We believe, due to variability in the data, findings of Sandberg (1980), and possible bias in the Miller-Newman data, that the effect of surface fuel consumption on duff consumption remains poorly quantified. Windspeed and shrub load were each regressed on percentage duff reduction after lower duff moisture for combinations of data. These variables were either nonsignificant or inconsequential.

The preliminary duff consumption guideline by Norum (1977), based largely on Lubrecht data, shows a strong influence of surface fuel loading on duff consumption that has not been verified by others. It may be appropriate for naturally occurring fuels but not in slash. Also, for many prescribed burning situations, especially where cutting activities have disturbed the ground, it seems unlikely that duff consumption would approach 100 percent (fig. 10).

Predicted by fire weather indices.—The best equations having NFDR 1,000-hour moisture as an independent variable were:

$$DR\% = 114.7 - 4.20\ TH \qquad (13)$$
$$(N = 71,\ r^2 = 0.55,\ se = 17.6)$$
$$DR\% = 111.4 - 4.69\ TH + 0.526\ WT3 \qquad (14)$$
$$(N = 119,\ r^2 = 0.58,\ se = 16.4)$$

Prediction from fire weather indices is imprecise, as illustrated by the wide scatter of data in figure 11. Surface fuel loading contributed little to explaining variation in percentage duff reduction and was secondary to NFDR 1,000-hour moisture, as shown by equation 14 and table 3. A change of 20 tons/acre (45 t/ha) changes percentage duff reduction by only 10 percent.

In an effort to improve the prediction of percentage duff reduction using NFDR 1,000-hour moisture, three sets of data were created by eliminating plots having at least 0.05, 0.10, and 0.25 inches of rain occurring over the past 5 days. This was expected to reduce variability between the NFDR 1,000-hour moisture and duff moisture and hence between NFDR 1,000-hour moisture and duff consumption. The coefficient of determination and standard error terms were improved slightly but not enough to be of practical importance:

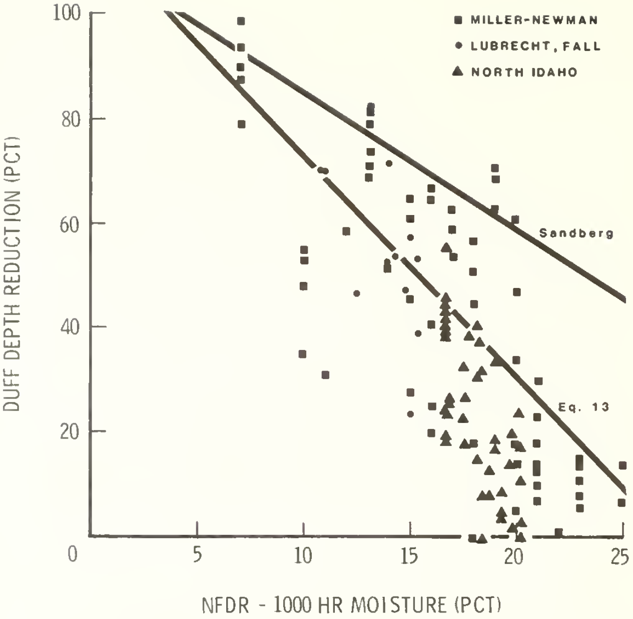

Figure 11.—Percentage duff depth reduction versus NFDR 1,000-hour timelag moisture content. Equation 13 and Sandberg's (1980) curves are graphed.

Data set	r^2	se	N
		Pct	
Eliminate 0.05 inch	0.64	16.1	87
Eliminate 0.10 inch	.59	16.7	104
Eliminate 0.25 inch	.60	16.4	111
All	.55	16.9	133

Similar minor improvements in precision were found for the relationships between duff depth reduction (inches) and NFDR 1,000-hour moisture.

Regression of percentage duff reduction on the Canadian Adjusted Duff Moisture Code, equation 15, was slightly less precise than on NFDR 1,000-hour moisture, equation 13:

$$DR\% = 21.2 + 0.293\ ADMC \qquad (15)$$
$$(N = 71,\ r^2 = 0.49,\ se = 18.9)$$

A linear relationship provided the best fit between percentage duff reduction and percentage mineral soil exposure:

$$DR\% = 15.2 + 0.948\ M\% \qquad (16)$$
$$(N = 66,\ r^2 = 0.85,\ se = 9.9)$$

Percentage Mineral Soil Exposure (M%)

The northern Idaho data were omitted from analyses of mineral soil because little of it was exposed by fire and the effect of logging disturbance on mineral soil could not be quantified. Duff spike observations at Miller-Newman and Lubrecht indicated no mineral soil exposure before burning. Logging disturbance did not complicate interpretation of data at these sites.

Predicted by duff moisture.—The best fit for the relationship between percentage mineral soil and lower duff moisture, using pooled data for Miller-Newman and

Lubrecht (fall), was provided by the following broken line regression (fig. 12):

$$M\% = \begin{matrix} 80.0 - 0.507 \text{ LDM, LDM} \leq 135 \text{ percent} \\ 23.5 - 0.0914 \text{ LDM, LDM} > 135 \text{ percent} \end{matrix} \qquad (17)$$

$(N = 72,\ r^2 = 0.58,\ se = 16.1)$

The break between regressions fell at 135 percent, which agrees reasonably well with observations by Sandberg (1980). Mineral soil exposure varied considerably when moisture content of lower duff was below 135 percent, resulting in imprecise predictions. For nonslash fuels, some improvement in prediction may be possible using equation 18:

$$M\% = 60.4 - 0.440 \text{ LDM} \qquad (18)$$

$(N = 11,\ r^2 = 0.53,\ se = 10.0)$

Lower duff moisture content in equation 17 and entire duff moisture content in the following equation were nearly equally effective as predictors of mineral soil exposure:

$$M\% = 167.4 - 31.6 \ln \text{EDM} \qquad (19)$$

$(N = 72,\ r^2 = 0.56,\ se = 16.4)$

When 0- to 3-inch woody fuel was added to regression, the best fitting equation included spring and fall fires:

$$M\% = 51.7 - 0.357 \text{ LDM} + 0.983 \text{ WT3} \qquad (20)$$

$(N = 80,\ r^2 = 0.55,\ se = 16.7)$

Equation 20 suggests that woody fuel loading has a greater influence on prediction of percentage mineral soil than on percentage duff reduction. A change of 1 ton/acre causes percentage mineral soil to change 1 percent. Although equation 20 performs reasonably well, the separate functions in figure 8 were suggested for application over equation 20 because they appear to fit the data better when lower duff moistures are greater than 100 percent and less than 30 percent (fig. 12).

Predicted by fire weather indices.—The relationship between percentage mineral soil and NFDR 1,000-hour moisture displayed considerable variation (fig. 13). Observations having low NFDR 1,000-hour moistures were scrutinized to explain why apparently dry duff was poorly consumed; however, explanations were not found.

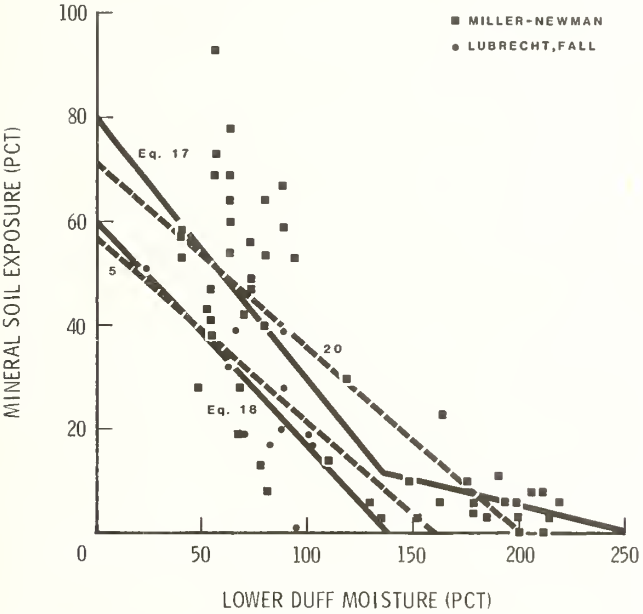

Figure 12.—Percentage mineral soil exposure versus lower duff moisture content. Equation 17 is for moderate to heavy slash and equation 18 primarily for nonslash. Equation 20 is shown for 5 and 20 tons/acre loadings of 0- to 3-inch woody fuel.

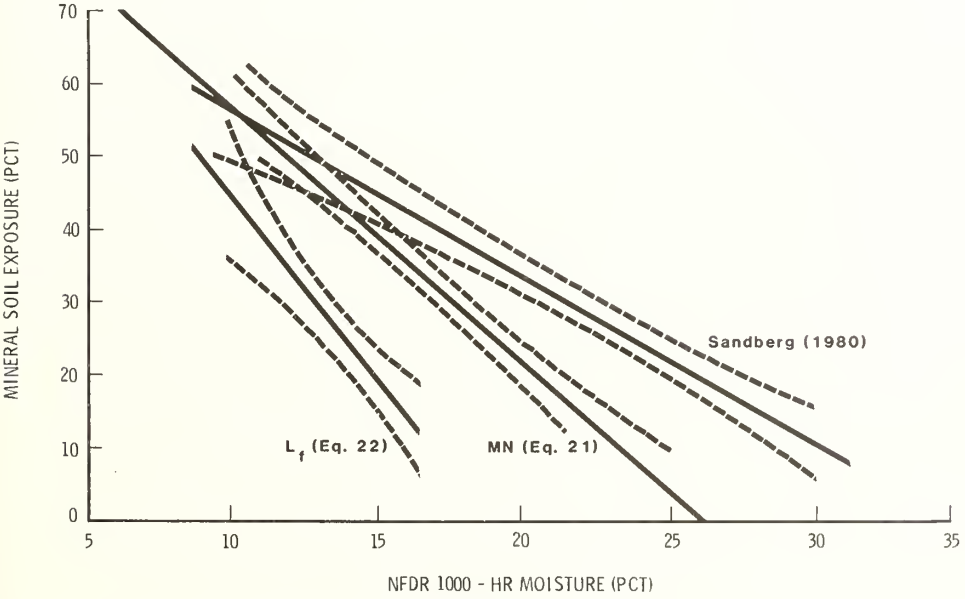

Figure 13.—Percentage mineral soil exposure versus NFDR 1,000-hour moisture content. Confidence bands (broken lines) are for one standard error of the mean.

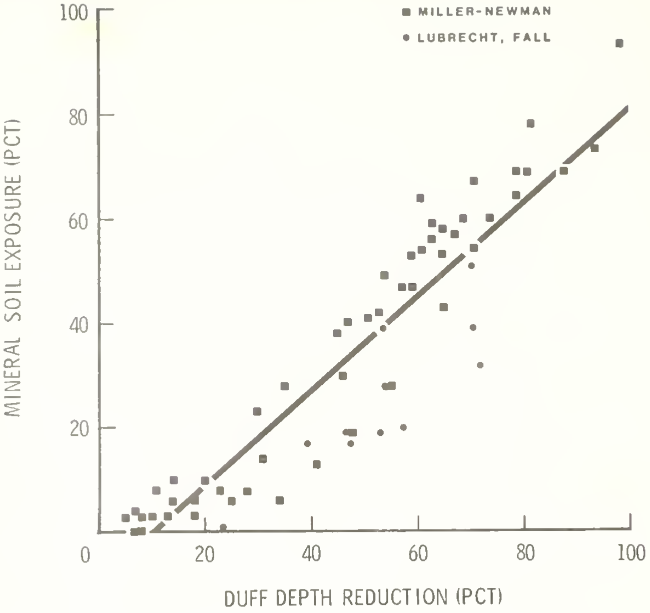

Figure 14.—Percentage mineral soil exposure versus percentage duff depth reduction. Equation 23 is graphed.

A function fitted to pooled data appeared unreasonable, thus equations for Miller-Newman and Lubrecht (fall) were derived separately:

$$M\% = 93.0 - 3.55\ TH, \text{ Miller-Newman} \qquad (21)$$
$$(N = 61,\ r^2 = 0.40,\ se = 20.3)$$

$$M\% = 94.3 - 4.96\ TH, \text{ Lubrecht fall} \qquad (22)$$
$$(N = 11,\ r^2 = 0.36,\ se = 11.7)$$

Addition of 0- to 3-inch woody fuel loading to regression analysis resulted in coefficients that were either nonsignificant or of very small consequence. Regression with a stratification of NFDR 1,000-hour moisture serving as dummy variables also failed to improve prediction over regression without dummy variables.

Predicted by percentage duff consumption.—The relationship between percentage mineral soil and percentage duff reduction, which is the reverse of figure 7, is described by:

$$M\% = -8.98 + 0.899\ DR\% \qquad (23)$$
$$(N = 66,\ r^2 = 0.85,\ se = 9.6)$$

This relationship (fig. 14) suggests that burnout of duff proceeds both downward and laterally. If duff burned only downward, little mineral soil would have been exposed until duff was reduced 40 percent or more, and this was not found. The pattern of burnout probably depends on moisture content of duff at microsites and heating from surface fire. Duff moisture content varies considerably over short distances (Hillhouse and Potts 1982), which complicates the burnout processes.

Other Independent Variables

Reaction intensity (Btu/ft^2/s), computed by Rothermel's (1972) fire spread model, was used as an independent variable in regression analysis for seven data set combinations. Reaction intensity was computed from loadings of 0- to 3-inch downed woody material, shrubs, and herbaceous vegetation; thus, it is a measure of surface fire intensity. Reaction intensity was either nonsignificant or weakly correlated with duff depth reduction, percentage duff depth reduction, and percentage mineral soil exposure. Overall, reaction intensity was not a useful predictor, which was not surprising because it represents energy release only from the propagating flame front.

Regression with Duff Moisture Code, Drought Code, and Adjusted Duff Moisture Code of the Canadian Forest Fire Weather Index (Van Wagner 1974) as independent variables showed the ADMC to be the best predictor of duff consumption. In all data sets analyzed, however, the NFDR 1,000-hour moisture provided a slightly more precise relationship with duff consumption than did the ADMC (appendix IV). The NFDR 1,000-hour moisture also was more highly correlated with lower duff moisture than were the Canadian duff moisture codes (appendix IV). This probably explains why it was a more precise predictor of duff consumption.

Testing Equations

Sandberg's (1980) research in partially cut Douglas-fir slash offered the only opportunity we found to compare findings involving the NFDR 1,000-hour moisture as a predictor. A comparison of equations derived in our study and by Sandberg for predicting percentage duff depth reduction are shown in figure 11. The differences between our findings and Sandberg's are large enough to be puzzling. Perhaps most of the difference would be eliminated if our data set contained higher observations of NFDR 1,000-hour moisture. A comparison of equations for predicting percentage mineral soil exposure shows reasonable agreement between Miller-Newman slash and Sandberg's slash over a portion of the independent variable (fig. 13). Again, however, the agreement between equations would probably be better if the range in data included larger values of NFDR 1,000-hour moisture. Figure 13 suggests that cutting activity may influence the relationship between mineral soil exposure and the NFDR 1,000-hour moisture.

The relationship between percentage mineral soil and percentage duff reduction reported by Sandberg (1980) agrees closely with ours. He fitted percentage duff reduction as a squared term. Our equation with percentage duff reduction as a squared term resulted in almost identical precision to the untransformed variable in equation 23.

Besides Sandberg's (1980) work in partially cut Douglas-fir slash, already discussed, several other studies on duff consumption were adequately documented for testing accuracy of equations. Predicted values from our equations were compared with values reported from the studies in table 4.

The performance of the equations is summarized in table 5. The number of tests per equation differed because information required for computing predictions was not equally available for all equations. Equation 2 for predicting duff depth reduction performed well (fig. 15). One observation by Ryan (1982) was underestimated

Table 4.—Description of studies used to test equations

Study	Location	Overstory type	Fuel	Number observations
Harrington (1981)	Santa Catalina Mtns., AZ	Ponderosa pine	Nonslash	6
Artley and others (1978)	Flathead N.F., MT	Larch/ Douglas-fir	Slash	6
Little and others (1982)	Willamette N.F., OR	Douglas-fir	Slash	2
Ryan (1982)	Flathead N.F., MT	Engelmann spruce, Douglas-fir, larch	Slash	2

Table 5.—Comparison of predicted values from selected equations with observed values from other studies. The variables are duff depth reduction (DR), percentage duff depth reduction (DR%), percentage mineral soil exposure (M%), lower duff moisture content (LDM), and entire duff moisture content (EDM)

Equation	Dependent variable	Independent variable	Number tests	Average observed	Average[1] difference	Average[2] percent difference
2	DR	LDM	10	0.76 inch	0.12 inch	-4
4	DR	EDM	4	.73 inch	.35 inch	63
8	DR%	LDM	16	38.3%	-2.8%	-24
9	DR%	LDM	16	38.3%	-1.2%	-14
10	DR%	EDM	4	21%	3.0%	39
17	M%	LDM	8	14.5%	6.6%	39
19	M%	EDM	4	14.5%	6.4%	37
23	M%	DR%	8	14.5%	4.3%	21

[1] Average of observed minus predicted values.

[2] Average of (observed minus predicted)/observed values expressed as percentage. One Ryan observation was omitted because it computed as an infinite difference.

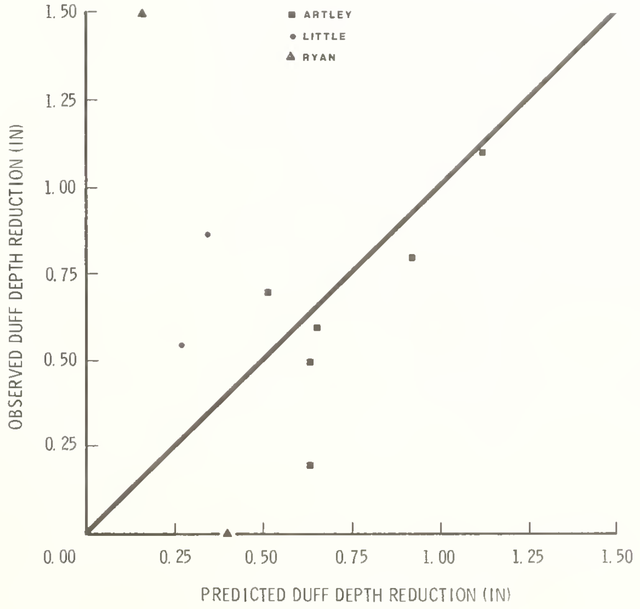

Figure 15.—Comparison of duff depth reduction values observed by Artley and others (1978), Little and others (1982), and Ryan (1982), table 4, with predictions from equation 2.

considerably, but not surprisingly, considering that approximately 25 tons/acre (56 t/ha) of large woody material was also consumed. It seems reasonable to expect increased duff consumption where burnout of large quantities of downed woody fuels provides prolonged heating of duff. Equation 9 for predicting percentage duff depth reduction performed well over a wide range (fig. 16). Particularly interesting was the close agreement between predictions and Harrington's (1981) observations in ponderosa pine. In contrast, the northern Idaho ponderosa pine was difficult to predict using any function. The reason for the disparity in fit is probably due in part to logging disturbance. Harrington's (1981) ponderosa pine stands were undisturbed, whereas the northern Idaho stands had been selectively logged. Possibly another difference is due to a greater preburn duff depth in Harrington's stands compared to northern Idaho where preburn duff depth was marginal for consistent combustion under any conditions.

Overall, the equations performed well. Most differences between observed and predicted values were within one standard error of the mean of the tested equations. These tests lend confidence to use of the equations over the broad range of conditions suggested in the section on Management Applications.

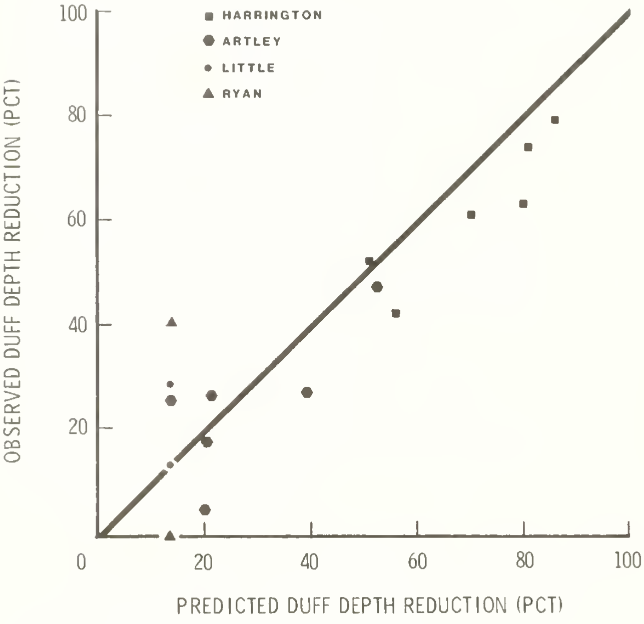

Figure 16.—Comparison of duff depth reduction values observed by Artley and others (1978), Harrington (1981), Little and others (1982), and Ryan (1982), table 4, with predictions from equation 9.

Small Woody Fuels

Absolute consumption.—As also reported by Norum (1976) and Beaufait and others (1977), amount of fuel consumed was strongly dependent on fuel loading before burning, table 6. Other independent variables analyzed were preburn loadings of shrubs, herbaceous vegetation, litter, and combinations of these; moisture content variables, windspeed, foliage remaining on slash, reaction intensity, and ignition method. All independent variables were either nonsignificant or contributed little to the consumption model beyond the contribution of preburn loading.

Percentage consumption.—Percentage consumption was weakly correlated with all independent variables studied. Even fuel moisture content, which strongly affects combustion, was a weak, often illogically correlated predictor, possibly because of bias in the Miller-Newman data. The limited moisture content measurements taken there prior to burning were highly variable and may have masked any true relationship between fuel consumption and moisture content.

A trend in percentage consumption, however, did appear (table 7). For moderate to heavy slash (MN), percentage consumption was uniformly high at 86 percent for 0- to 1-inch and 81 percent for 0- to 3-inch woody fuels. For light woody fuels (NI and L), percentage consumption varied substantially and averaged 48 percent for 0- to 1-inch and 46 percent for 0- to 3-inch. Based on the range in data (table 2), a high percentage consumption can be expected for 0- to 3-inch preburn loadings greater than about 10 tons/acre and variable but less consumption for loadings under about 10 tons/acre. This is consistent with a state-of-knowledge review by Martin and others (1979) who reported that slash consumption in clearcuts averaged 70 to 90 percent for small woody fuels. Observations in nonslash fuels from the Western United States varied considerably.

Large Woody Fuels

Consumption of large woody fuels, like small woody fuels, related closely to preburn fuel loadings. Lower duff moisture content and the NFDR 1,000-hour moisture entered as second independent variables were either nonsignificant or illogically correlated. The best equation based on Lubrecht was:

$$CWTLG = -2.7 + 0.79\ WTLG \quad (32)$$
$$(N = 20,\ r^2 = 0.72,\ se = 6.64)$$

Both absolute and percentage consumption for the Lubrecht data were weakly and inconclusively correlated with NFDR 1,000-hour moisture and lower duff moisture. The relationship between percentage consumption and large fuel load was also vague. Plotted northern Idaho data revealed a lack of relationships among percentage consumption and the independent variables (including TH, WTLG, and WT3). Due to this and the narrow range in large fuel loadings, further analyses were not attempted.

Table 6.—Equations for consumption of 0- to 1-inch (CWT1) and 0- to 3-inch (CWT3) downed woody fuels as functions of preburn loading of 0- to 1-inch (WT1) and 0- to 3-inch (WT3) downed woody fuels

Equation number	Data source	r^2	se	100 (se) / y	n	Range in preburn loading	Equations
			Tons / acre			Tons / acre	
24	Miller - Newman	0.94	0.464	7.6	65	3.44 - 14.80	CWT1 = 0.195 + 0.831 WT1
25	Miller - Newman	.82	2.008	12.6	65	12.84 - 35.80	CWT3 = −1.24 + 0.873 WT3
26	Lubrecht	.76	.198	44.2	20	.55 - 2.13	CWT1 = −0.496 + 0.920 WT1
27	Lubrecht	.75	.831	64.0	20	1.33 - 7.68	CWT3 = −1.751 + 0.925 WT3
28	Northern Idaho	.94	.363	53.8	48	.03 - 10.27	CWT1 = −0.278 + 0.926 WT1
29	Northern Idaho	.93	.415	52.6	48	.10 - 11.06	CWT3 = −0.396 + 0.918 WT3
30	All studies	.98	.416	12.6	133	.03 - 14.80	CWT1 = −0.269 + 0.890 WT1
31	All studies	.97	1.503	18.2	133	.10 - 35.80	CWT3 = −0.670 + 0.845 WT3

Table 7.—Preburn and consumed loadings for 0- to 1-inch and 0- to 3-inch downed woody fuels

	Mean		Standard deviation		Coefficient of variation	
Fuel	MN	L, NI	MN	L, NI	MN	L, NI
0- to 1-inch load					---- Percent ----	
Preburn, tons/acre	7.13	1.03	2.29	1.30	32	126
Consumed, tons/acre	6.12	.61	1.96	1.25	32	205
Consumed, percent	86.2	48.1	7.4	35.4	8.6	74
0- to 3-inch load						
Preburn, tons/acre	19.68	1.88	4.88	1.84	25	98
Consumed, tons/acre	15.94	.94	4.70	1.58	30	168
Consumed, percent	80.6	45.5	10.6	33.3	13	73

Percentage consumption from diameter reduction.—Sandberg and Ottmar (1983) developed a method of estimating percentage volume reduction based on the relationship between diameter reduction and NFDR 1,000-hour moisture. The relationship was derived from experimental burns in cable-yarded logging slash.

Although their method was based on slash, we tested it using Norum's nonslash Lubrecht data. Predicted unit consumption was computed using root-mean-squared diameter and NFDR 1,000-hour moisture in their algorithm (Sandberg and Ottmar 1983). Observed values were percentage consumption unit averages. The model substantially underpredicted percentage consumption as shown in the following tabulation of averages:

	Observed	Predicted	Difference
Mean	64	28	36
Range	0 to 99	16 to 50	−25 to 80

The underprediction is probably due to a high degree of rot in the fuels at Lubrecht and perhaps more contact between fuel pieces and the forest floor. At Lubrecht, 85 percent of the large fuels were classed as rotten (can be kicked apart with the foot). Rotten fuels were excluded from Sandberg and Ottmar's analysis. This may explain the greater than predicted consumption at Lubrecht, because burnout of rotten fuel should be more complete than sound fuel. Contact with a smoldering forest floor would also enhance burnout of large woody pieces. Fuels in place for long periods such as the naturally accumulated ones at Lubrecht would normally have more contact with duff than logging slash.

Sandberg and Ottmar's model was further tested using two slash fires (Ryan 1982). Results were a small overprediction (8 percent) for sound fuel and a large underprediction (42 percent) for rotten fuel. These tests certainly indicate that adjustments to Sandberg and Ottmar's model are needed if it is applied to rotten large woody fuels.

CONCLUSIONS

This paper provides land managers a quantitative means of predicting duff and woody fuel consumption that can be especially useful in planning prescribed fires. Tests of the duff consumption relationships against other data suggest wide application is possible. The predictions should be reasonably accurate where duff is continuous and averages more than 0.5 inch (1.3 cm) deep. Application of results is not recommended in open stands where duff is discontinuous.

Duff moisture content was by far the most influential variable on duff consumption. Loadings of small woody fuels also influenced duff consumption but to a lesser extent. Quantification of this influence remains poorly understood. The NFDR 1,000-hour moisture related more closely to duff consumption than did the Canadian duff moisture codes. The NFDR 1,000-hour moisture should be helpful for developing fire prescriptions. The relationship between percentage mineral soil exposure and percentage duff reduction indicates that duff consumption involves both downward and lateral movement of the combustion interface. Consumption of small woody fuels can be explained simply as most of these fuels are consumed (80 to 90 percent) wherever fire spreads.

To improve knowledge for predicting and understanding fuel consumption, the primary factors influencing large fuel burnout on a practical area basis need to be identified and their relationships to consumption quantified. The relationships between duff consumption, logging disturbance, and consumption of small and large woody fuels need better definition. The need for more precise knowledge to predict duff consumption will grow as future utilization leaves less woody surface fuel to support fire and as prescribed fire objectives become more closely tied to integrated land management objectives.

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APPENDIX I. ADJUSTING FUEL DIAMETER CLASSES

In all studies, loadings of downed woody material were determined using the planar intersect method where counts of particles by diameter class are converted to loadings (Brown 1974). To convert particle count data from 0- to 0.4-inch (0- to 1-cm) and 0.4- to 4-inch (1- to 10-cm) classes used in the Miller-Newman study to the conventional classes, it was assumed that the frequency of fuel pieces by diameter could be represented by a single probability distribution (fig.17). The relative frequency of intercepts in the diameter classes in (A) was partitioned into the diameter classes in (B) (fig. 17) using data on diameters from randomly intersected particles.

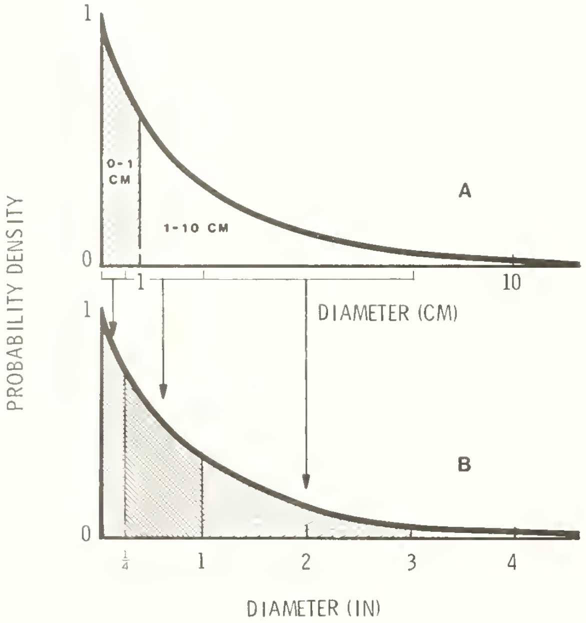

Figure 17.—Fuel particle diameter distributions showing the size classes used at Miller-Newman (A) and the conventional diameter classes used in the other studies (B).

Allocating intercepts to the 0- to ¼-inch class.—Using data from a study by Brown and Roussopoulos (1974), it was determined that 95 percent of the intercepts in the 0- to 0.4-inch class were less than one-fourth inch. The adjusted frequency for the 0- to ¼-inch class is then 0.95 times the frequency of intercepts in the 0- to 0.4-inch class. It follows that the remaining intercepts in the 0- to 0.4-inch class would be part of the ¼- to 1-inch class.

Allocating intercepts to the ¼- to 1-inch class.—This class includes intercepts from the upper end of the 0- to 0.4-inch class and a portion of the 0.4- to 4-inch class. The proportion of fuel pieces between 0.4 and 1 inch was calculated by species using intercept data from the Miller Creek and Newman Ridge Study (table 8). The allocation of intercepts at a given sample point can be expressed by:

$$Y_1 = 0.05\, X_1 + X_2 \left(\sum_{j=1}^{8} P_j R_{j,1}\right)$$

where

Y_1 = frequency of intercepts allocated to the ¼- to 1-inch class

X_1 = sample frequency for the 0- to 0.4-inch class

X_2 = sample frequency for the 0.4- to 4-inch class

P_j = fraction of slash estimated to be the jth species

$R_{j,1}$ = fraction of jth species 0.4- to 4-inch class that is 0.4 to 1 inch.

Allocating intercepts to the 1- to 3-inch class.—This class is the mid-portion of the 0.4- to 4-inch class. It can be expressed as:

$$Y_2 = X_2 \left(\sum_{j=1}^{8} P_j R_{i,2}\right)$$

where

Y_2 = frequency of intercepts allocated to the 1- to 3-inch class

$R_{i,2}$ = fraction of the jth species 0.4- to 4-inch class that is 1 to 3 inches.

Table 8.—Fractions of particle intercepts by species and diameter classes at Miller Creek and Newman Ridge

Species	Diameter classes 0.4 to 1 inch (1 to 2.5 cm)	 1 to 3 inches (2.5 to 7.6 cm)	 3 to 4 inches (7.6 to 10 cm)
Western larch	0.43	0.55	0.02
Douglas-fir	.44	.51	.05
Subalpine fir	.53	.44	.03
Grand fir	.53	.44	.03
Lodgepole pine	.44	.50	.06
Engelmann spruce	.71	.28	.01
Ponderosa pine	.63	.36	.01
Western redcedar	.63	.36	.01

APPENDIX II. CORRELATIONS AMONG VARIABLES

Table 9.—Simple correlation coefficients[1] between transformed and untransformed duff consumption variables

Dependent variable	Independent variables											
	EDM	1/EDM	LDM	1/LDM	TH	WT3	ln (WT3)	RI	ADMC	DPRE	DR%	ln (DR%)
Miller – Newman												
DR	−0.791	0.777	−0.811	0.749	−0.793	−0.181	−0.159	0.108	0.664	0.132		
ln DR	−.740	.671	−.768	.673	−.674	−.053	−.029	.203	.520	.244		
$\sqrt{DR}$	−.829	.787	−.857	.774	−.794	−.151	−.130	.154	.638	.140		
DR%	−.840	.813	−.853	.795	−.749	−.167	−.148	.143	.647	−.114		
ln DR%	−.830	.753	−.847	.753	−.691	−.118	−.090	.198	.544	.002		
$\sqrt{DR\%}$	−.862	.810	−.878	.801	−.739	−.156	−.133	.171	.609	−.082		
M%	−.738	.769	−.785	.738	−.635	−.281	−.255	.040	.534	−.011	0.928	0.791
ln M%	−.780	.765	−.843	.758	−.642	−.282	−.261	.067	.499	−.076	.887	.820
$\sqrt{M\%}$	−.774	.783	−.832	.764	−.645	−.291	−.267	.048	.518	−.047	.922	.821
Lubrecht fall												
DR	−.445	.160	−.367	.163	−.670	.727	.615	.916	.379	.839		
ln DR	−.453	.213	−.385	.215	−.648	.642	.565	.824	.348	.770		
$\sqrt{DR}$	−.454	.189	−.379	.191	−.662	.687	.591	.875	.363	.812		
DR%	−.573	.477	−.613	.493	−.598	.463	.371	.709	.525	.360		
ln DR%	−.472	.402	−.530	.422	−.532	.453	.399	.639	.494	.308		
$\sqrt{DR\%}$	−.525	.441	−.574	.460	−.568	.460	.386	.677	.512	.336		
M%	−.616	.653	−.727	.679	−.597	.137	.005	.442	.677	.041	.849	.832
ln M%	−.352	.346	−.462	.376	−.412	.311	.299	.428	.510	.075	.845	.919
$\sqrt{M\%}$	−.509	.521	−.624	.551	−.529	.235	.156	.460	.618	.069	.886	.912
Lubrecht spring and fall												
DR	−.107	.037	−.322	.195	−.645	.680	.574	.520	.448	.518		
ln DR	−.031	.021	−.301	.205	−.632	.586	.517	.360	.441	.407		
$\sqrt{DR}$	−.072	.032	−.316	.203	−.643	.636	.549	.443	.446	.466		
DR%	−.140	.217	−.493	.421	−.610	.449	.365	.204	.515	.060		
ln DR%	−.071	.159	−.461	.373	−.562	.387	.321	.080	.472	−.016		
$\sqrt{DR\%}$	−.104	.187	−.478	.397	−.589	.422	.348	.144	.497	.022		
M%	−.276	.428	−.572	.598	−.588	.244	.137	.132	.560	−.133	.900	.867
ln M%	−.149	.268	−.442	.411	−.398	.240	.186	.023	.338	−.203	.820	.840
$\sqrt{M\%}$	−.194	.335	−.507	.499	−.489	.270	.192	.087	.430	−.176	.879	.871
Northern Idaho												
DR	−.182	.038			−.541	.021	.272	.131	.525	.734		
ln DR	−.169	.089			−.528	−.068	.249	.086	.531	.706		
$\sqrt{DR}$	−.269	.144			−.589	.026	.312	.184	.581	.144		
DR%	−.371	.300			−.656	.047	.346	.256	.665	.489		
ln DR%	−.413	.349			−.602	.082	.370	.281	.612	.360		
$\sqrt{DR\%}$	−.405	.337			−.634	.066	.360	.274	.645	.419		

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[1] Significance levels for r at 90 and 95 percent levels listed respectively are 0.211 and 0.250, MN; 0.521 and 0.602, L_f; 0.389 and 0.456, L_s; and 0.243 and 0.288, NI.

APPENDIX III. EQUATIONS IN METRIC UNITS

Table 10.—Metric units for equations and related statistics on precision and bias

Equation number	Data source	Equation[1]	Std. error	Root mean square (O − P)			
				MN	L_f	L_s	NI
			Centimeters				
1	MN, L_f	DR = 2.612 − 0.0225 LDM + 0.417 DPRE	0.80	0.75	0.97	1.88	—
2	MN	DR = 4.574 − 0.0201 LDM	.87	.86	1.78	1.26	—
3	MN, L_f	DR = 2.238 − 0.0244 EDM + 0.439 DPRE	.85	.80	1.00	2.19	2.33
4	MN	DR = 4.272 − 0.0215 EDM	.91	.90	1.92	1.38	2.90
5	MN, L_f	DR = 6.854 − 0.263 TH	1.05	.90	1.56	1.17	1.32
6	MN, L_f, NI	DR = 4.503 − 0.267 TH + 0.399 DPRE	.78	.91	.93	1.73	.50
7	MN, L_f	DR = 1.04 + 0.0179 ADMC	1.16	1.01	1.71	.69	1.64
			Percent				
8	MN, L_f	DR% = 87.8 − 0.390 LDM	14.1	14.4	11.5	28.5	—
9	MN, L_f	DR% = 97.1 − 0.519 LDM, LDM ≤160% = 13.6, LDM >160%	13.5	13.6	11.6	27.8	—
10	MN, L_f	DR% = 83.7 − 0.426 EDM	14.7	14.9	11.7	33.1	51.3
11	MN, L_f, L_s	DR% = 75.8 − 0.397 LDM + 0.2927 WT3	15.2	14.6	12.3	19.6	—
12	L_f	DR% = 70.2 − 0.384 LDM + 1.660 WT3	10.5	59.4	8.9	22.2	—
13	MN, L_f	DR% = 114.7 − 4.20 TH	17.6	18.2	11.7	26.9	19.3
14	MN, L_f, NI	DR% = 111.4 − 4.69 TH + 0.2347 WT3	16.4	19.3	11.9	18.5	12.4
15	MN, L_f	DR% = 21.2 + 0.293 ADMC	18.9	19.6	12.2	17.2	23.4
16	MN, L_f	DR% = 15.2 + 0.948 M%	9.9	8.0	15.7	5.4	—
17	MN, L_f	M% = 80.0 − 0.507 LDM, LDM ≤ 135% = 23.5 − 0.0914 LDM, LDM > 135%	16.1	15.7	17.0	28.3	—
18	L_f	M% = 60.4 − 0.440 LDM	10.0	27.3	9.1	17.4	—
19	MN, L_f	M% = 167.4 − 31.6 ln (EDM)	16.4	16.5	14.6	33.5	—
20	MN, L_f, L_s	M% = 51.7 − 0.357 LDM + 0.4386 WT3	16.7	17.3	9.2	16.8	—
21	MN	M% = 93.0 − 3.55 TH	20.3	20.0	21.3	32.2	—
22	L_f	M% = 94.3 − 4.96 TH	11.7	30.9	10.6	14.4	—
23	MN, L_f	M% = −8.98 + 0.899 DR%	9.6	7.9	15.2	7.5	—
			t/ha				
24	MN	CWT1 = 0.437 + 0.831 WT1	1.039	1.019	1.366	1.456	1.210
25	MN	CWT3 = −2.779 + 0.873 WT3	4.500	4.429	1.612	2.265	2.220
26	L	CWT1 = −1.112 + 0.920 WT1	.444	1.120	.427	.427	.944
27	L	CWT3 = −3.924 + 0.925 WT3	1.862	4.620	1.572	1.974	3.164
28	NI	CWT1 = −0.623 + 0.926 WT1	.813	.549	.628	.673	.809
29	NI	CWT3 = −0.887 + 0.918 WT3	.930	5.926	3.094	3.877	.919
30	MN, L, NI	CWT1 = −0.602 + 0.890 WT1	.932	1.075	.583	.628	.809
31	MN, L, NI	CWT3 = −1.501 + 0.845 WT3	3.368	4.422	2.175	2.958	1.256
32	L	CWTLG = −6.05 + 0.79 WTLG	14.9	—	—	—	—

[1] DR, DPRE: cm
WT1, WT3, WTLG, CWT1, CWT3, CWTLG: t/ha.

APPENDIX IV. COMPARING FIRE WEATHER INDICES

Table 11.—Statistics for comparing regression relationships between fire weather indices and duff consumption

Data set	DC		DMC		ADMC		TH	
	r^2	se	r^2	se	r^2	se	r^2	se
			Duff Depth Reduction					
		Inch		*Inch*		*Inch*		*Inch*
L_f	0.05	0.71	0.14	0.67	0.12	0.68	0.45	0.54
MN	.30	.49	.44	.44	.54	.40	.63	.36
MN, L_f	.28	.55	.34	.51	.48	.47	.58	.43
NI	.28	.26	.28	.26	.28	.26	.29	.26
L_f, NI	.61	.39	.33	.51	.40	.47	.68	.35
All	.08	.57	.33	.49	.37	.48	.55	.42
			Duff Depth Reduction					
		Pct		*Pct*		*Pct*		*Pct*
L_f	0.00	15.3	0.28	13.0	0.26	12.7	0.36	12.3
MN	.23	23.1	.28	22.3	.49	19.9	.56	18.5
MN, L_f	.15	24.4	.44	19.9	.53	18.2	.61	16.6
NI	.44	11.3	.44	11.3	.45	11.2	.43	11.4
L_f, NI	.54	12.6	.51	13.0	.56	12.6	.64	11.5
All	.03	24.2	.43	18.9	.42	18.7	.59	16.1
			Mineral Soil Exposure					
L_f	0.01	14.6	0.46	10.8	0.44	11.0	0.36	11.7
MN	.23	23.1	.28	22.2	.35	21.1	.40	20.4
MN, L_f	.03	24.5	.29	21.0	.33	20.3	.37	19.8
			Lower Duff Moisture Content					
MN, L	—	—	0.30	45.5	0.39	42.3	0.53	37.1

U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10527

Brown, James K.; Marsden, Michael A.; Ryan, Kevin C.; Reinhardt, Elizabeth D. Predicting duff and woody fuel consumed by prescribed fire in the Northern Rocky Mountains. Research Paper INT-337. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 23 p.

Relationships for predicting duff reduction, mineral soil exposure, and consumption of downed woody fuel were determined to assist in planning prescribed fires. Independent variables included lower and entire duff moisture contents, loadings of downed woody fuels, duff depth, National Fire-Danger Rating System 1,000-hour moisture content, and Canadian Duff Moisture Codes. Results apply to a number of mesic forest cover types.

KEYWORDS: fuel consumption, duff, downed woody fuel, forest fuels, prescribed fire

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Research Paper
INT-338

April 1985

Nutrient Release from Mount St. Helens Volcanic Ash and Retention by Western Montana Soil

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CLEMSON UNIVERSITY
SEP 5 1985
PUBLIC DOCUMENTS

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ACKNOWLEDGMENTS

The authors are grateful to Ron Barger and Roger Hungerford for assistance with this research. Financial support by the USDA Forest Service, Intermountain Forest and Range Experiment Station, is gratefully acknowledged.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

RESEARCH SUMMARY

Three soils of a wide fertility range, based on tree growth and soil chemistry, were covered by 0.4, 1, and 1.9 inches (1, 2.5, and 5 cm) of volcanic ash on the surface and leached for an equivalent of 3 years of rainfall (28.9 inches or 73 cm/year), along with an ashless control. The volcanic ash released a substantial amount of most biologically essential ions with the first leaching, but amounts released were lower with successive leachings. The three soils stored the most ions during the first leaching. Weathering of the ash did not appear to occur rapidly or result in acceleration of ion release. The least fertile soil retained the most ions, but there was no increase in conifer growth from the nutrients added through leaching of the volcanic ash. Soils with high calcium and magnesium levels lost some of these ions during leaching. The poorest soil showed some increase in calcium after treatment with ash and water. Sodium and potassium showed similar leaching and storage patterns. All soils lost potassium, but some small and insignificant increases in calcium were found after ash and water treatment. Phosphate was stored from only the heaviest ash application. Some of the original soil phosphate was lost, but heavier application of ash did result in slightly significant increases in available soil phosphorus. Nitrate losses tended to increase toward the end of the leaching trials. Increased nitrification could account for greater nitrate losses, but mineralization and nitrification did not fall within the scope of this study. The ash is capable of storing copper from incoming water but did not selectively remove other ions. For some soils, ion storage or loss was more easily explained than for others. These three soils with different pH, bulk density, and chemistry responded to the addition of low levels of ions differently. Some ions were stored more effectively when deeper ash layers were applied. Others tended to lose more ions with greater ash depth. The Coram soil (calcareous) did improve in lettuce production with 0.4 and 1 inch of ash added to the surface. The most fertile soil improved slightly in lettuce growth potential with the addition of ash on a short-term basis (3 months). Ash depths of over 1.9 inches may alter aeration and appear to reduce growth of both lettuce and conifers in the greenhouse.

Nutrient Release from Mount St. Helens Volcanic Ash and Retention by Western Montana Soil

Nellie M. Stark
Don A. Essig

INTRODUCTION

The eruption of Mount St. Helens on May 18, 1980, left stages of chaos in the affected area. The devastation of the immediate impact area has created special ecological problems. The ashfall may be considered a natural fertilization or mulching process in less severely impacted areas such as western Montana. Could the 0.7 to 1.1 inches (2 to 3 cm) of ashfall in western Montana benefit tree growth?

The question is particularly important because of the possibility of future eruptions and fallout and the subsequent ecological effects.

Studies have shown changes in particle sizes in fallout with distance from Mount St. Helens (Ogren and others 1981; Chuan and others 1981; Farlow and others 1981; Danielson 1981). Studies on the chemical composition of the recent ashfall have shown variations in particle chemistry with distance from the volcano (Hobbs and others 1981; Inn and others 1981; Gandrud and Lazrus 1981; Vossler and others 1981). Ash is a potential natural fertilizer because it contains most of the ions needed for plant growth. Some ions are readily water soluble and available whereas others will be released after weathering.

In western Montana, soils with a wide range of natural fertility received about 0.78 inch (2 cm) of ashfall. This study examined the interaction of ions from the ash with three soils to determine if the addition of ash would significantly increase soil fertility to a level that might later reflect improved tree growth. Lack of water most often limits tree growth in western Montana, but on soils where nutrients are limited, the possibility exists that ashfall might improve future productivity. This may warrant special management practices such as using different spacing to increase the amount of root zone water and nutrients available to trees so that improved fertility could most favorably influence growth during the growing season. Ashfall could increase the available water retention in soils as well. The influence of ashfall on the physical aspects of soils was beyond the scope of this research, but with deep ashfall, considerable physical effects would be expected.

A previous study (Stark and Zuuring 1981) showed that adding one nutrient to soil in solution may result in predictable levels of storage or loss, or the loss of other ions. These relationships need to be examined with regard to volcanic ash and soils of varying fertility. Our research questions were:

1. What ion concentrations would be released from volcanic ash over prolonged leaching, equivalent to 3 years of rainfall?
2. How would three chemically and physically different soils store or lose ions with ion additions from ash and simulated precipitation?
3. What are the consequences of ashfall on forest soils relative to tree growth?

ASH AND SOIL COLLECTION SITES

Large quantities of local volcanic ash were not available. Therefore, unleached, fresh volcanic ash from Moses Lake, WA (contributed by Dr. Raymond Murray, geologist) was collected and homogenized in large plastic bags. Particle sizes for the ash were mostly 0.05 to 53 microns (Farlow and others 1981), which is similar to the size range at Missoula (0.16 to 53 microns).

One area from Lolo Pass, MT, has extremely poor granitic soils with a B horizon cation exchange capacity (CEC, Black 1965) of 3 to 4.2 meq/100 g and a moderate water-holding capacity determined by pressure plate extraction (11 percent, 1/3 minus 15 bars). The soils, from 4,600 ft (1 402 m) elevation, were removed from a depth of 15.7 inches (40 cm). These loamy skeletal soils belonging to the Selway Series are derived from the Idaho batholith and are Frigid Dystric Eutrocrepts. They are low in available ions, have an acid pH of 5.7 to 5.9, are overlain by 8 inches (20 cm) of andic cap, but are not droughty. The bulk density of the ash was 0.8 g/cc and that of the underlying soil ranged from 1.0 to 1.4 g/cc. Annual air temperatures range from −36 to 95 °F (−38 to 35 °C) with 42 inches (1 070 mm) of annual precipitation, mostly snow. Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) is the area's main species, with radial growth averaging 55 rings/inch (22/cm). Ground vegetation is sparse.

The second soil collection site is the Coram Experimental Forest near Glacier Park in western Montana. The soils have some limestone inclusions and are moderately fertile with a pH of 7.9 to 8.1. Almost all conifer species of the region grow on these soils. Precipitation averages 31 inches (787 mm), mostly snow. Lack of water does not normally limit growth, at least in early summer. The soils are derived from argillite, impure limestone, and quartzite with some volcanic ash (Klages and others 1976). The bulk density of the mineral soil is 0.9 to 1.1 g/cc and the mean CEC in the B horizon is 13 meq/100 g. The soils are cryocrepts of the Felan series (andeptic Cryoboralfs or Eutroboralfs). Tree growth averages 11 rings/inch (4.4/cm) in the sampling area for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco, unmanaged stand). The ground vegetation is dense and vigorous with generally good growth. Annual air temperatures range from −24 to 93 °F (−31 to 34 °C). Sampling was at 3,986 ft (1 215 m) elevation.

The third site, a south slope in the Lubrecht Experimental Forest, is classed as a Typic Eutroboralf (Frigid). Annual air temperatures range from −40 to 105 °F (−40 to 40 °C), with 17.5 inches (447 mm) of precipitation, mostly snow (Steele 1981). The bulk density ranges from 1.3 to 1.6 g/cc. The site is at 4,019 ft (1 225 m) elevation and supports Douglas-fir, ponderosa pine (*Pinus ponderosa* Laws.), and western larch (*Larix occidentalis* Nutt.). Growth for pine averages 9 rings/inch (3.5/cm). The CEC of the B horizon is 21 meq/100 g of soil, and the pH ranges from 6.2 to 6.5. These are soils of moderate fertility, and lack of water limits growth, mainly in August.

EXPERIMENTAL PROCEDURES

Undisturbed soil cores could not be obtained in these rocky soils. Therefore, each lot of soil was homogenized separately to prepare a uniform medium for leaching. The soils, with separate bags of litter and duff, were collected from three areas. Topsoil (A horizon) and subsoil (B horizon) were kept separate and replaced in the cylinders in their natural sequence. Coarse fragments >0.4 inch (>1 cm) in diameter were removed, along with coarse organic debris. Forty PVC tubes 8 by 25.6 inches (20 by 65 cm) were filled with 20 inches (50 cm) of each soil type. To approximate the natural soil condition, each column contained 1.9 to 3.9 inches (5 to 10 cm) of A horizon on top with 15.7 to 17.7 inches (40 to 45 cm) of B horizon beneath. Uniform packing was used to reestablish something resembling the original soil density. The soil-filled cylinders were dropped on end onto a flat surface 10 times from 3.9 inches (10 cm) height to achieve uniform packing. The bottom of each tube was covered by clean muslin to act as a filter and retain the soil. Tube bottoms were set in large plastic pots fitted with Tygon tubing to act as a drain for leachate from the tubes. The tubes were set on leaching benches and litter and duff placed on the surface to the depth normal for each soil, 0.39 to 0.78 inch (1 to 2 cm) (fig. 1). Soil and litter volume equaled approximately 446 in^3 (7 308 cm^3). The 40 tubes of each soil were divided into four treatments of 10 tubes each. The treatments were: control—no ash added, 0.4 inch (1 cm) of ash added, 1 inch (2.5 cm) of ash added, and 1.9 inches (5 cm) of ash added over a 20.5-in^2 (133-cm^2) surface area. The volumes of ash added to the soil were 8.1 in^3 (133 cm^3) for the 0.4-inch depth of ash, 20.5 in^3 (337 cm^3) for 1-inch depth, and 40.5 in^3 (633 cm^3) for the 1.9-inch depth. Chemical characterization of the soils appears in table 1.

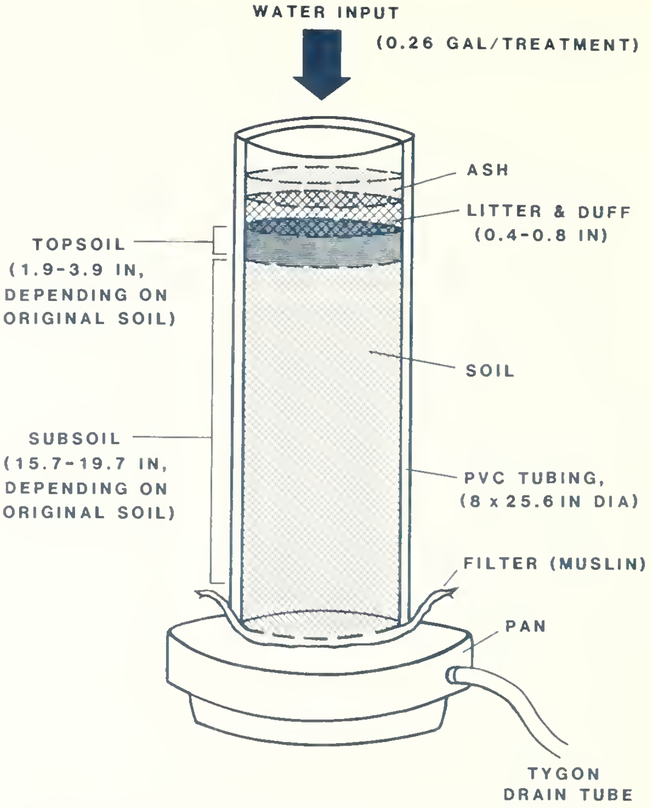

Figure 1.—Diagram of leaching apparatus. Forty such tubes were used with each soil, totaling 120 tubes set in drainage racks.

One liter of water (2.9 inches or 7.3 cm depth in the cylinders) was applied to each cylinder once a week for the first 10 weeks and every other week thereafter from November 18, 1980, to November 2, 1981, for a total of 30 leachings. All tubes were initially saturated and the first leaching completed and analyzed chemically before the ash was applied. The first week (0) represents leaching before ash was added to the surface. A total of 86.6 inches (220 cm) depth, 7.3 cm/treatment of water was applied to each cylinder, the equivalent of 3 years of precipitation as a mean for the three sites (28.9 inches or 73 cm/year). Air temperatures during leaching remained above freezing, but ranged with the seasons from 34 to 86 °F (1 to 30 °C).

Greenhouse leaching tests of this type cannot be expected to create leaching conditions or tensions in the soil column that are identical to field conditions. Therefore, results cannot be extrapolated to field situations without reservations. This study could not have been conducted in the field with the appropriate ash depths. The work is intended to explore trends in leaching losses from three soils if they did receive ashfalls of the three depths.

Large quantities of distilled water were not available for this study. Because the local tap water approximates the ion content quality of natural rain water (table 2),

Table 1.—Mean and standard deviation for the ion content of the 1N ammonium acetate soil extracts as μg/g before and after an equivalent of 3 years of leaching with no ash and 0.4, 1, and 1.9 inches of ash on the litter surface, as ppm, and as meq/100g for original soil before leaching

Soil and element	After leaching (B horizon)								Before leaching[1,2] (B horizon)		
	No ash		0.4 inch		1 inch		1.9 inches				
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	meq/100g
	ppm										
Lolo											
Ca	601	22	596	31	589	44	596	37	407	97	2
Fe	.9	.14	1.2	1.1	1.0	.2	105	10	1.2	1.9	.006
K	101	5.8	110	5.9	105	4.5	105	6.4	146	37	.37
Mg	106	3.3	103	4.2	101	2.7	108	5.2	90	18	.7
Mn	2.3	.7	2.6	.5	2.3	.4	2.3	.6	2.2	.28	.01
Na	47	10.4	61	19.5	34	5.6	37	5.9	46	8	.2
Si	113	17.7	96	36	52	23	647	17.0	—	—	—
Zn	.4	.1	.3	.2	.2	.05	.4	.06	.3	.3	.0009
Cu	.1	0	.1	0	.1	0	.1	0	.1	0	0
									Calculated base sat. = 78%		
Coram											
Ca	8,259	39	8,323	47	8,474	57	8,526	44	8,000	2,100	40
Fe	1.0	.3	.9	.05	1.0	.09	1.0	.3	1.4	1.0	.007
K	286	6.6	280	4.0	274	8.9	275	6.5	260	80	.66
Mg	282	5.3	280	3.3	276	4.2	276	4.5	269	124	1.0
Mn	4.5	1.1	4.5	1.1	5.1	.8	4.3	.6	2.3	.9	.01
Na	41	12.4	46	13.7	44	13.6	54	15.1	42	10	.04
Si	144	29.7	125	41.9	157	84.8	202	54.6	—	—	—
Zn	.15	.1	.20	.1	.24	.1	.12	.09	1.0	.4	.001
Cu	.2	0	.2	0	.2	0	.2	0	.2	0	0
									Calculated base sat. = >320%[3]		
Lubrecht											
Ca	3,460	63	3,505	52	3,470	40	3,520	94	3,568	90	17.8
Fe	.9	.2	.9	.1	.9	.1	1.1	.1	.6	.2	.003
K	1,158	16.9	1,172	18.1	1,153	17.0	1,187	9.5	1,160	70	2.9
Mg	494	6.0	491	10.2	478	6.1	476	10.4	480	10	3.9
Mn	1.4	.5	1.5	.5	1.7	.3	1.9	.3	1.2	.9	.006
Na	87	6.4	88	4.4	94	4.6	101	4.6	56	30	.24
Si	264	54	268	50	284	54	289	57	—	—	—
Zn	.1	.03	.08	.02	.09	.03	.16	.09	1.0	.2	.003
Cu	.1	0	.1	0	.15	0	.1	0	.12	0	0
									Calculated base sat. = 118%[3]		

---

[1] Depth 8 to 12 inches (20 to 30 cm).

[2] "Before leaching" figures are taken as small subsamples from the area studied and are not necessarily comparable to the actual soils used; they will not reflect before and after chemical conditions of the **same** soil column. The "before" leaching data represent the natural variations of soils while the "after," "no ash" control represents the results from homogenized soil samples.

[3] The 320 percent base saturation recorded for the Coram soil and the 118 percent for the Lubrecht soil are artifacts of the soil extraction procedure. Ammonium acetate (1N) will remove soluble Ca and exchangeable Ca resulting in erroneously high extractable Ca data. These soils are thought to be normally <50 percent base saturated.

Table 2.—Range of ion levels found in western Montana precipitation and tap water

Source	Ca	Cu	K	Mg	Na	NO_3
	ppm					
Precipitation[1]						
Low	0.3	0.05	0.02	0.01	0.04	0.9
High	5.6	.04	.32	.06	.05	2.2
Tap water						
Low	2.2	1.2	2.8	7.0	7.1	1.0
High	45.4	6.8	3.5	15.5	11.5	2.2

[1] Note that most forest soils receive throughfall that often has up to 10 times higher ion concentrations than occur in precipitation.

tap water was used to simulate the influence of natural precipitation. This made it possible to study the influence of ion interactions natural to rain water that would not occur in measurable amounts in distilled water. If the exchange sites were saturated with divalent ions, elevated levels of calcium in the tap water would show up in the leachate. If many exchange sites were occupied by monovalent $H+$, the calcium ions would be stored. Failure of soils to store ions when the exchange sites were or were not saturated could be examined using tap water but would not have been possible with distilled water. Large fluctuations in tap water quality occurred only twice during the study, following major storms (weeks 5 and 16). The water used was analyzed for all 11 ions studied with each leaching to approximate the atmospheric ion inputs.

The leachate collected from each cylinder was subsampled the day following application and, using atomic absorption spectroscopy, analyzed for calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), and zinc (Zn). Phosphate was determined colorimetrically using the ammonium molybdate-stannous chloride method (APHA 1971). Phosphate levels were often below the detection limit (<0.05 ppm) and complicated by the varying turbidity of the samples. Nitrate and pH were determined by specific ion analyzer (EPA 1974). The levels of iron, manganese, zinc, and phosphate stored were so low that these ions are excluded from discussion in this paper.

Equivalent volumes of ash were leached with water for 30 weeks, and for each treatment the leachate was analyzed to determine the levels of ions coming out of the ash and entering the soil. Input of ions from ash was added to the input from the tap water. Net weekly ion loss from the soil or gain to the soil was plotted. The study was not designed to establish complete ionic balances for these soils.

After leaching of the soils was concluded, two successive crops of Simpson's black-seeded lettuce were planted in each tube, watered regularly, and harvested at maturity for short-term bioassay (dry weight). The dry weights of lettuce were used to judge if the soils had improved in fertility after an equivalent of 3 years of leaching with three depths of volcanic ash on the surface. Lettuce dry weights and foliar nutrient content were compared using t-tests to those of the controls (no ash added but leached 30 weeks with tap water).

Four species of conifers—lodgepole pine, ponderosa pine, western larch, and Douglas-fir—were grown in tubes with ash in a greenhouse to test the longer term influence of ash on tree seedling growth. Small tubes were filled with either Lubrecht or Lolo soil (no Coram soil was available), and 0, 0.4 inch (1 cm), 1 inch (2.5 cm), or 1.9 inches (5 cm) of ash was added to the surface. Soil samples were from 7.8 to 15.7 inches (20 to 40 cm) depth. Pregerminated seeds of each species were added to the top and watered. Seedling heights were measured for each soil and ash depth and the t-test was used to determine if height differences were significant. Seedling heights were measured at the end of the first and second growing seasons, and seedling condition was recorded as good, fair, or poor depending on color, growth, and the development of new needles. Only water was added every 2 days during the growing season.

Subsamples of soil from each of the 120 tubes were analyzed after a year of leaching to determine whether the loss or gain of ions to the soil would show up as differences in 1N ammonium acetate extractable ions available to these plants, or if they had been complexed in less available form. These extracts were analyzed using an inductively coupled plasma spectrometer for 16 ions (table 1). This instrument was acquired after the column leachings began and therefore was not used for leachate analysis.

STATISTICAL TESTS OF LEACHATE AND SOILS

The concentrations of Ca, Cu, H, K, Mg, Na, and NO_3 in soil leachate and ammonium acetate extracts of each soil after leaching were tested using analysis of variance. Data for each soil were treated separately to compare the ion concentrations in leachate and soil extracts under each ash depth, including a control. The ANOVA table:

Source	df	MS	F
Trt	3	MS_{trt}	$F=\frac{MS_{trt}}{MS_{error}}$
Error	36	MS_{error}	
Total	39		

Data were not compared statistically between soil types because of obvious differences in chemistry. The leachate data were summed for the entire period of the tests to estimate net ion storage or loss. In testing for homogeneity of variances, each ion had to qualify at the 0.05 level for two of three tests (Cochran's C, Bartlett-Box F, and Hartley's). The homogeneity of variance was rejected if an ion failed more than one of these tests.

All ions from soil and leachate that showed homogeneous variances are included. Ion concentrations were then tested at the 0.05 significance level with Duncan's MRT and Fischer LSD methods of multiple comparisons. The LSD results for each ion from leachate or soil were used only if they differed from the Duncan test and if group sizes were unequal. This was the case only for Coram calcium summed net leachate data.

Weekly ion loss or gain to each soil was also plotted to show trends with time. Seedling height growth was tested using t-tests and analysis of variance.

RESULTS FOR SEVEN IONS

The following are research results on ion additions and ion loss or storage by soil for selected ions. Ion release is addressed first for each ion, then ion loss or storage from soil is discussed.

Hydrogen

The ash released hydrogen for 2 weeks and then assumed a steady but low release of H+ (figs. 2A,B).

Hydrogen ion levels in the leachate from Lolo soils tended to be relatively uniform over the period of the tests (figs. 2A,B). The major fluctuation at week 1 for the 1.9-inch (5-cm) ash treatment shows that the soils took up the hydrogen ions added from the ash. Storage did not persist beyond the first week, nor was it followed by a peak ion loss. Differences between treatments were small. Hydrogen ion storage and loss was almost identical for all three soils tested.

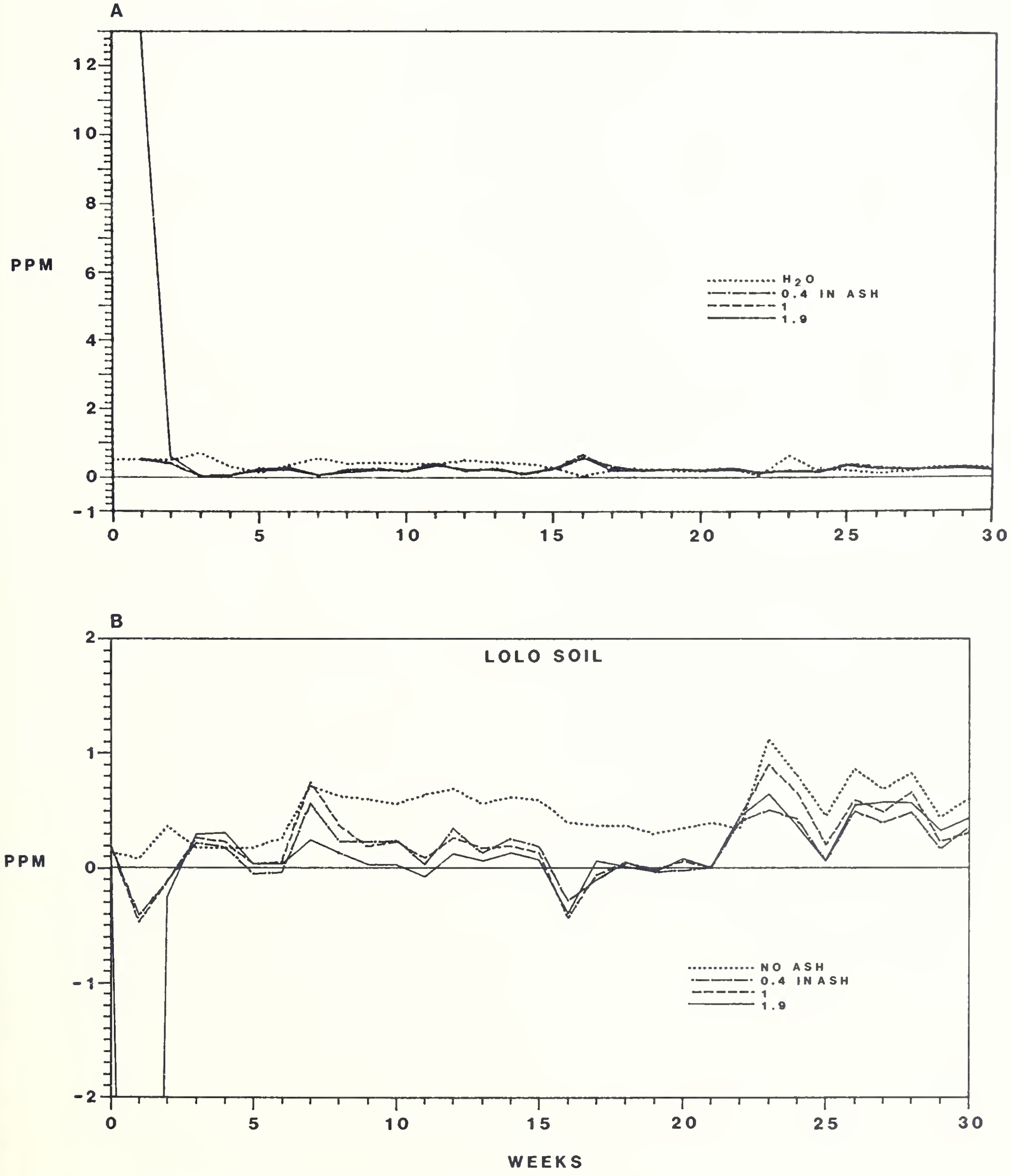

Figure 2.—Input (A) and loss or storage (B) of hydrogen as ppm × 10^{-4} for Lolo Pass soil. The pattern from other soils was identical to that from Lolo.

Calcium

Calcium release from the ash was high for the first 5 weeks for all treatments. High levels of calcium were added by the water on the 5th and 16th weeks from storms. Otherwise, the ash and water added low amounts of calcium after the first 5 weeks (fig. 3A).

Calcium storage and loss patterns were similar for all three soils. The Lubrecht soil was intermediate in storage and loss. The Coram soil showed variability in calcium release over time. Lolo soils stored over 40 ppm Ca when it was available. This shows that the exchange sites were not saturated and small additions of calcium from water (or rain water) are easily stored. The Lolo soil, which was originally low in Ca (407 μg/g, table 1, fig. 3B), had greater net Ca storage than either of the other soils, with only minor calcium losses (6 μg/g maximum for any treatment). This soil has a low base saturation, allowing Ca storage. The Coram soils that initially had 8 259 μg Ca/g compared to 407 μg Ca/g of Lolo soil, lost Ca throughout the study regardless of treatment (table 1, fig. 3C). The Coram soils lost Ca consistently after the third week of leaching. The ammonium acetate extractant used removed more calcium than was actually on the exchange sites for the Coram and Lubrecht soils, resulting in data that showed over 100 percent base saturation (figs. 3B,C, table 1). Even the control soil lost Ca, indicating that initially there were considerable amounts of water-soluble calcium in the soil. This soil appears to be able to control Ca losses with prolonged leaching because fluctuations in loss were lower and more steady after week 16. Lubrecht soils (fig. 3D) stored Ca initially (week 1) and during heavy runoff (weeks 5 and 16), which produced high Ca (46-48 ppm) in the tap water. This occurred in spite of the fact that the soil extraction (table 1) showed the soil exchange sites to be already saturated. Obviously, the extraction of soil with 1N ammonium acetate is not dependable for some soils. Note the differences that were needed in scale to accommodate large differences in soil chemistry. The extraction energies of water and ammonium acetate are commonly hypothesized to be different (Black 1965), yet the ammonium acetate method is the main one acceptable for soils.

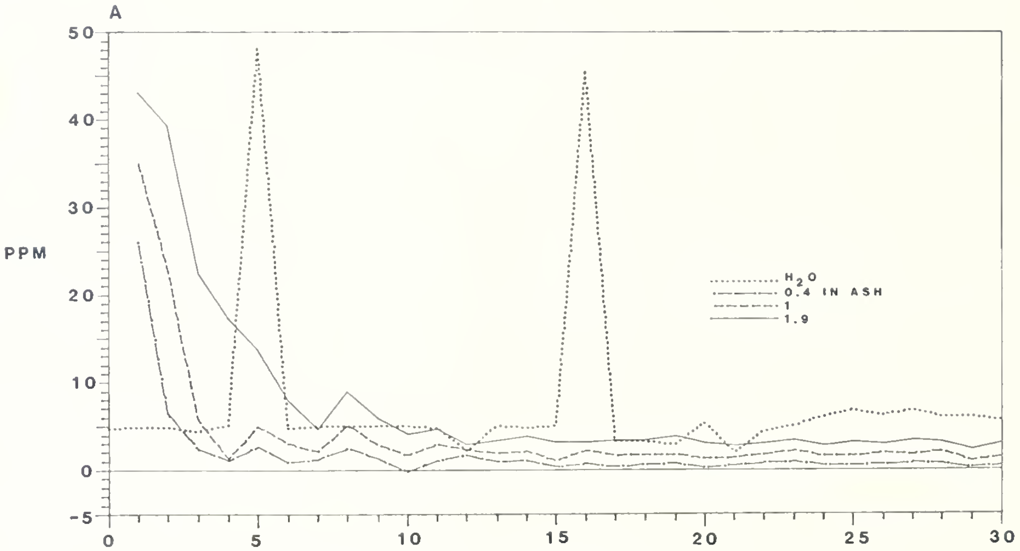

Figure 3.—Input of calcium from water and ash (A) and storage (−) and/or loss (+) of calcium for Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

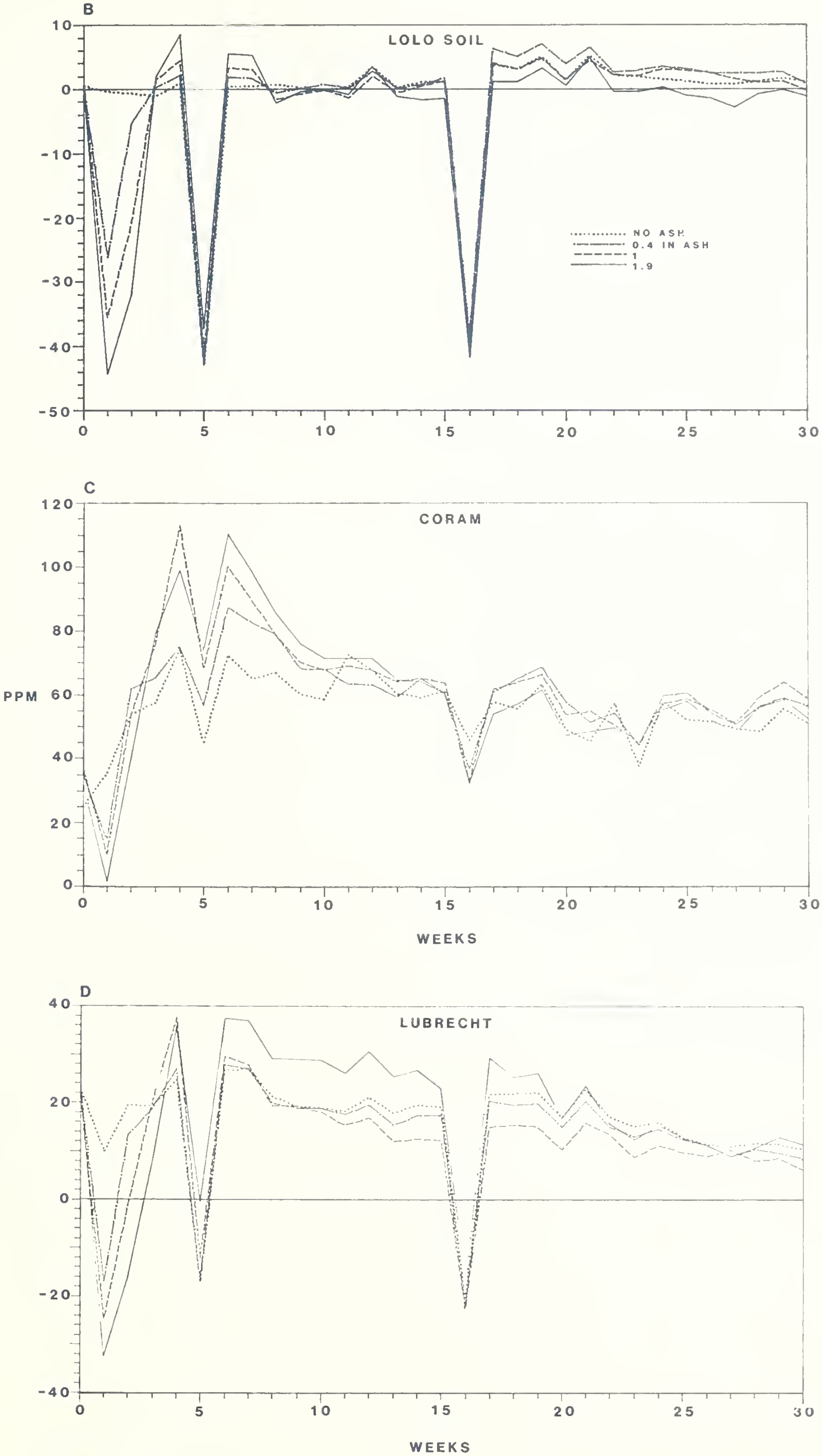
B
LOLO SOIL
10
0
-10
-20
-30
-40
-50
NO ASH
0.4 IN ASH
1
1.9
0
5
10
15
20
25
30
C
CORAM
120
100
80
PPM
60
40
20
0
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
40
20
0
-20
-40
0
5
10
15
20
25
30
WEEKS

Figure 3.—(Con.)

Copper

Copper leached from the ash for the first 4 weeks, but loss then declined to low levels (fig. 4A). Tap water normally has high levels of Cu.

Copper storage and loss were almost identical between Lubrecht, Coram, and Lolo soils (figs. 4B,C,D). Net leachate often showed storage of Cu by ash-treated soils, but the ash actually removed Cu from the tap water. This made it appear that the soil was storing Cu when in fact the ash was storing the Cu. Actual soil storage would occur only when the water input of copper exceeded the storage capacity of the ash. The levels of Cu were low but above the detection limits. Perhaps this ash-stored Cu will be released to the soil in the future. The storage capabilities of ash for copper would not have been detected with distilled water. Ammonium acetate extraction removed only low levels of Cu (0.1 to 0.2 ppm) from any of the three soils (table 1).

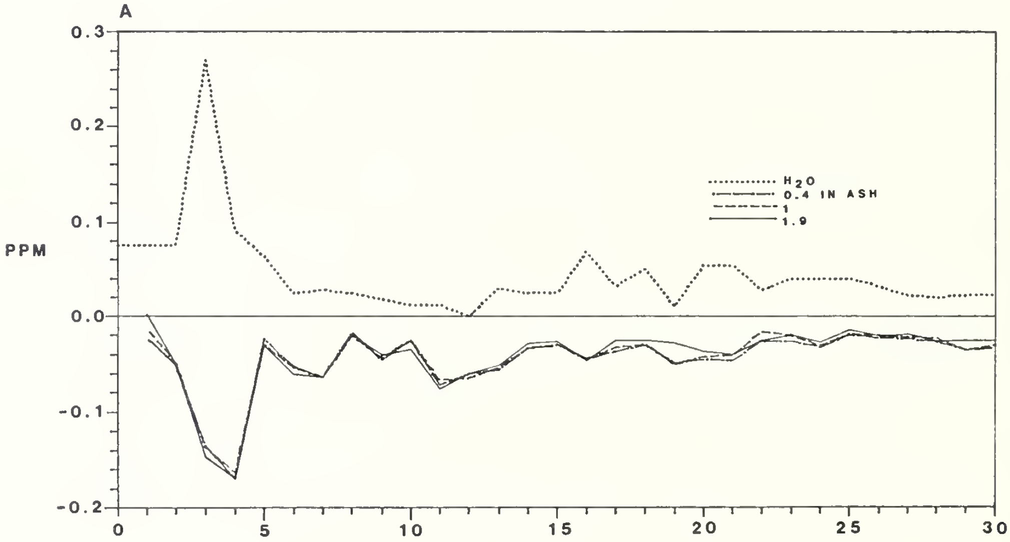

Figure 4.—Input of copper from water and ash (A) and storage (—) and/or loss (+) of copper from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

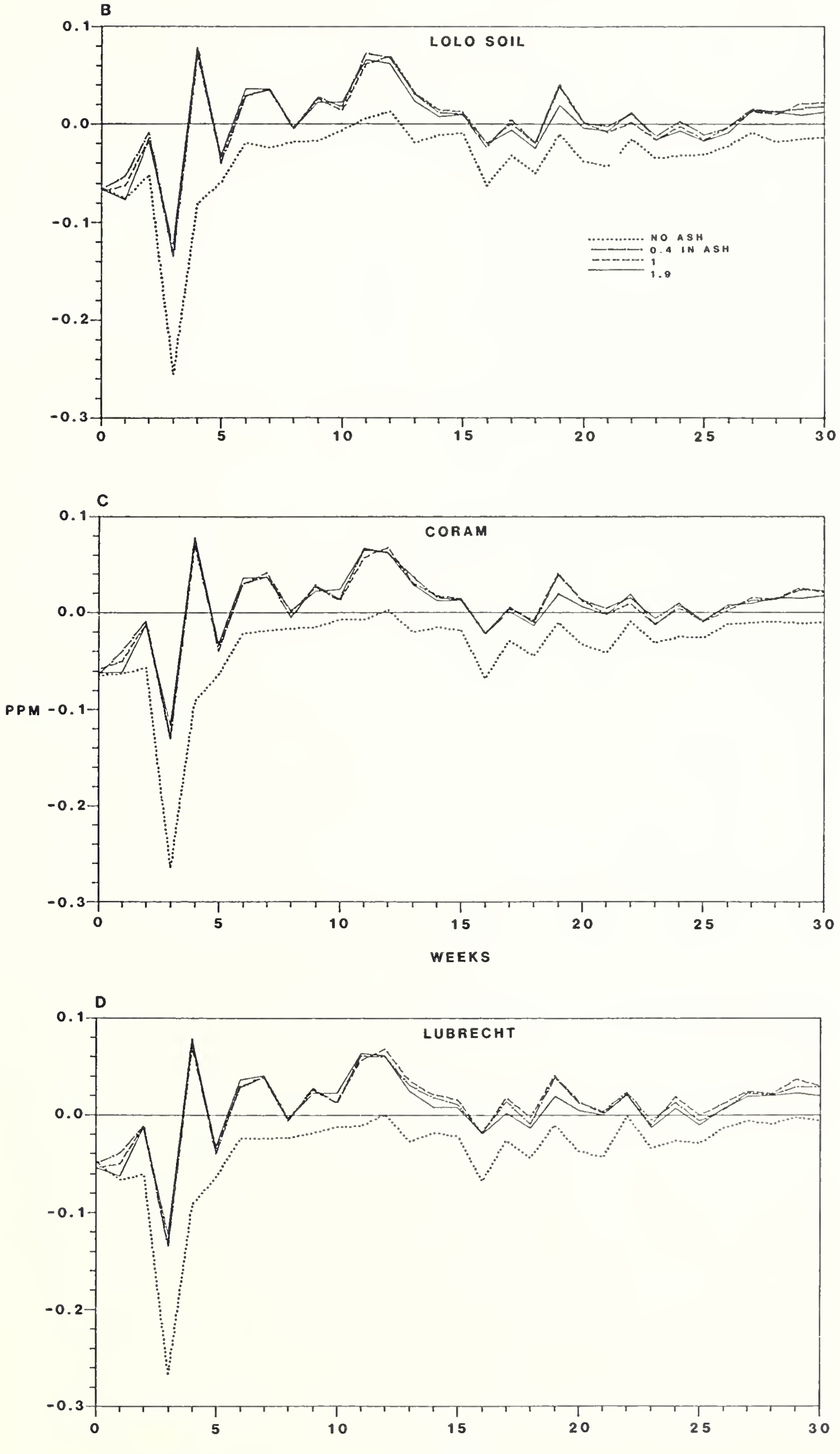
B
0.1
0.0
-0.1
-0.2
-0.3
LOLO SOIL
NO ASH
0.4 IN ASH
1
1.9
0
5
10
15
20
25
30
C
CORAM
PPM
WEEKS
D
LUBRECHT

Figure 4.—(Con.)

Potassium

The highest levels of K were released from ash during the first three leachings. Losses from ash thereafter were low and regular (fig. 5A).

All three soils showed similar behavior with K added from ash (figs. 5B,C,D). After the initial peak of K input from the ash treatments, no K storage occurred in any of the three soils. The magnitude of net K loss from these soils is surprising and unexplained. The storage of calcium by the Lolo soil and the base saturation data (table 1) suggest that the exchange sites are not saturated in the Lolo soil so that ion storage should be possible. The base saturation of the Lubrecht and Coram soils is misleading because of the extracting agent normally used with soil. The authors suspect that the soils were not base saturated initially, but the exchange sites were flooded with calcium solubilized by the extracting solution. However, potassium is monovalent and has a relatively weak affinity for cation exchange sites, making it especially mobile and susceptible to leaching loss in the presence of excess divalent calcium.

Coram soils showed low storage of K (0.4 ppm) during the first week after losses from the pretreatment leaching (fig. 5C). Net losses of K from soil are of concern because this ion is often scarce.

Potassium losses from Lolo soils followed the pattern for H and Na (see figs. 2B and 7B)—the more ash applied, the more K stored during the first week. After week 1, net losses of K occurred from all Lolo treatments, with greatest losses from the controls. The soils may have been unable to store more K because of K or Ca saturation, or K may be poorly held by these soils. The activation energy of water for Ca is high, supporting the second explanation.

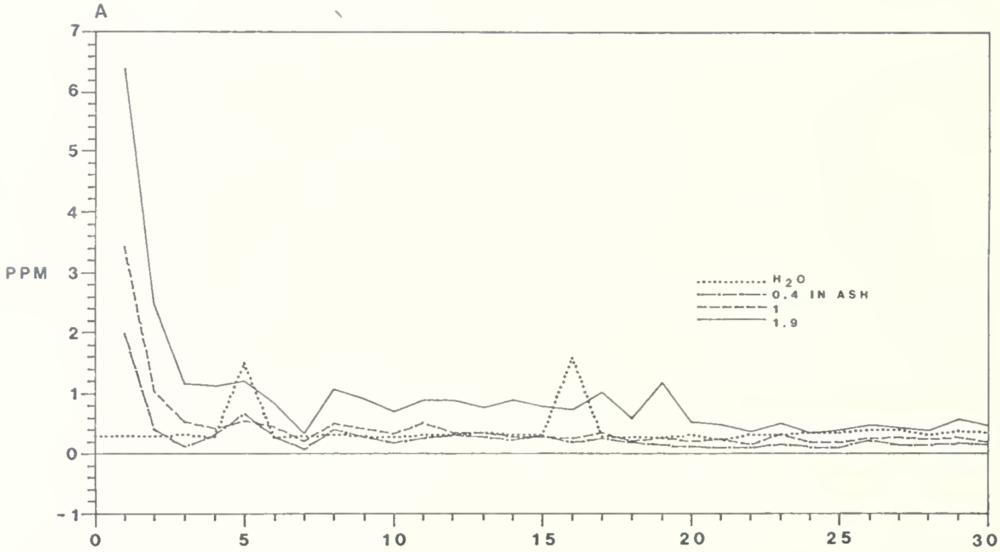

Figure 5.—Input of potassium from water and ash (A) and storage (−) and/or loss (+) of potassium from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

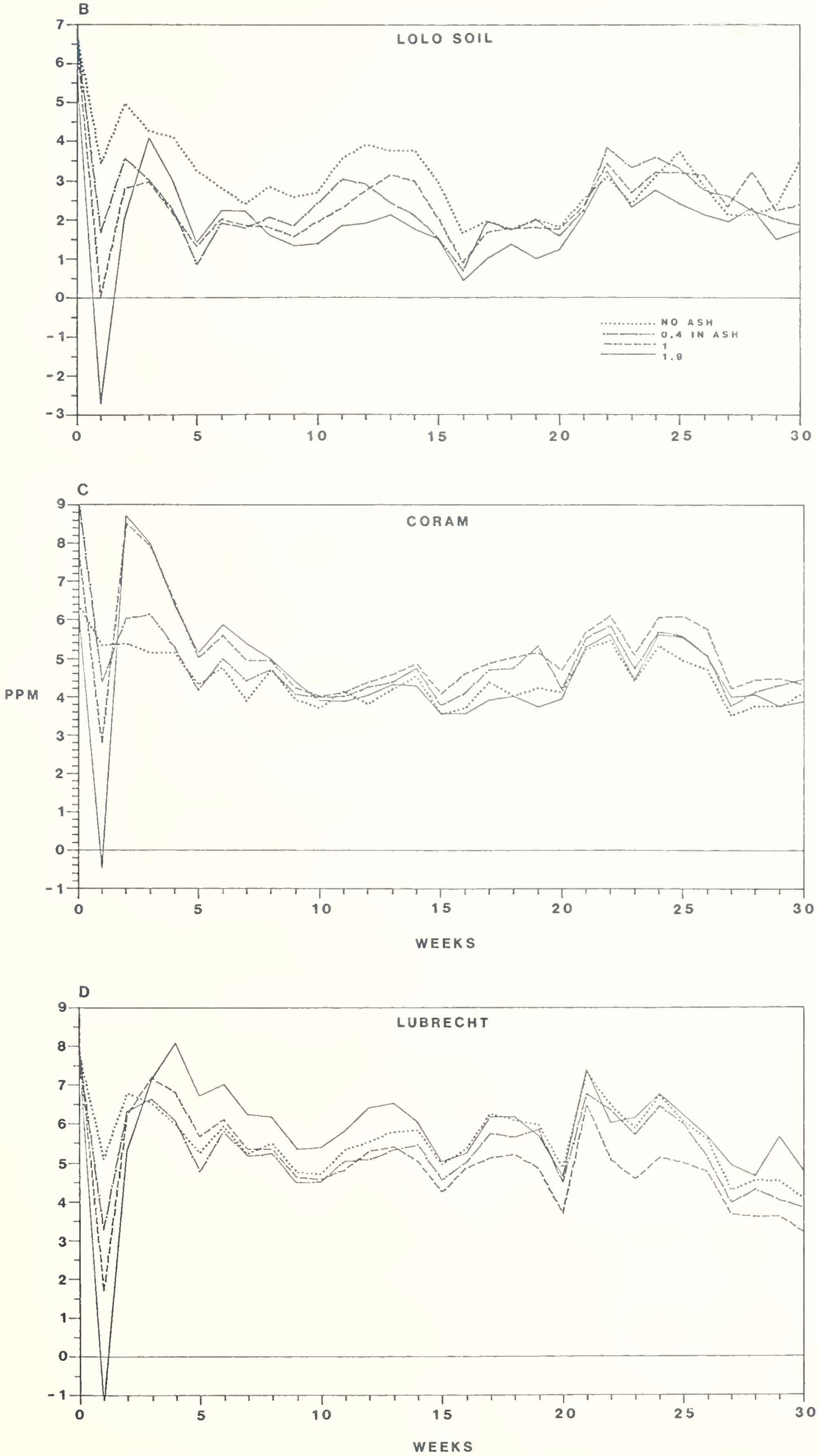
B
LOLO SOIL
7
6
5
4
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
NO ASH
0.4 IN ASH
1
1.9
C
CORAM
9
8
7
6
5
PPM
4
3
2
1
0
-1
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
9
8
7
6
5
4
3
2
1
0
-1
0
5
10
15
20
25
30
WEEKS

Figure 5.—(Con.)

Magnesium

All ash treatments released the most magnesium during the first 3 weeks of leaching (fig. 6A).

Magnesium followed a pattern of fluctuation similar to that of calcium but with the actual concentrations lower, as expected. Magnesium inputs from water in weeks 5 and 16 resulted in magnesium storage by all three soils in those weeks. The Lolo soil showed little loss of Mg but the greatest storage (figs. 6B,C,D). This soil was the lowest in Mg (90 μg/g, table 1). Lubrecht soils were again intermediate. Coram soils, initially high in Mg, stored no Mg after the first week of leaching (fig. 6C,D). High Mg inputs at weeks 5 and 16 resulted in the same storage or reduction in loss as seen with Ca and should be interpreted likewise.

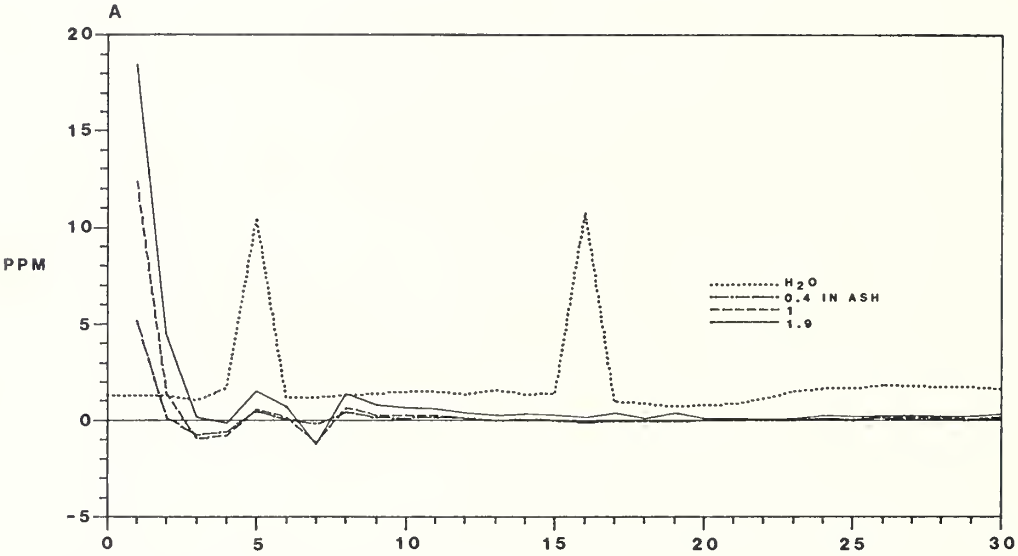

Figure 6.—Input of magnesium from water and ash (A) and storage (−) and/or loss (+) of magnesium from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

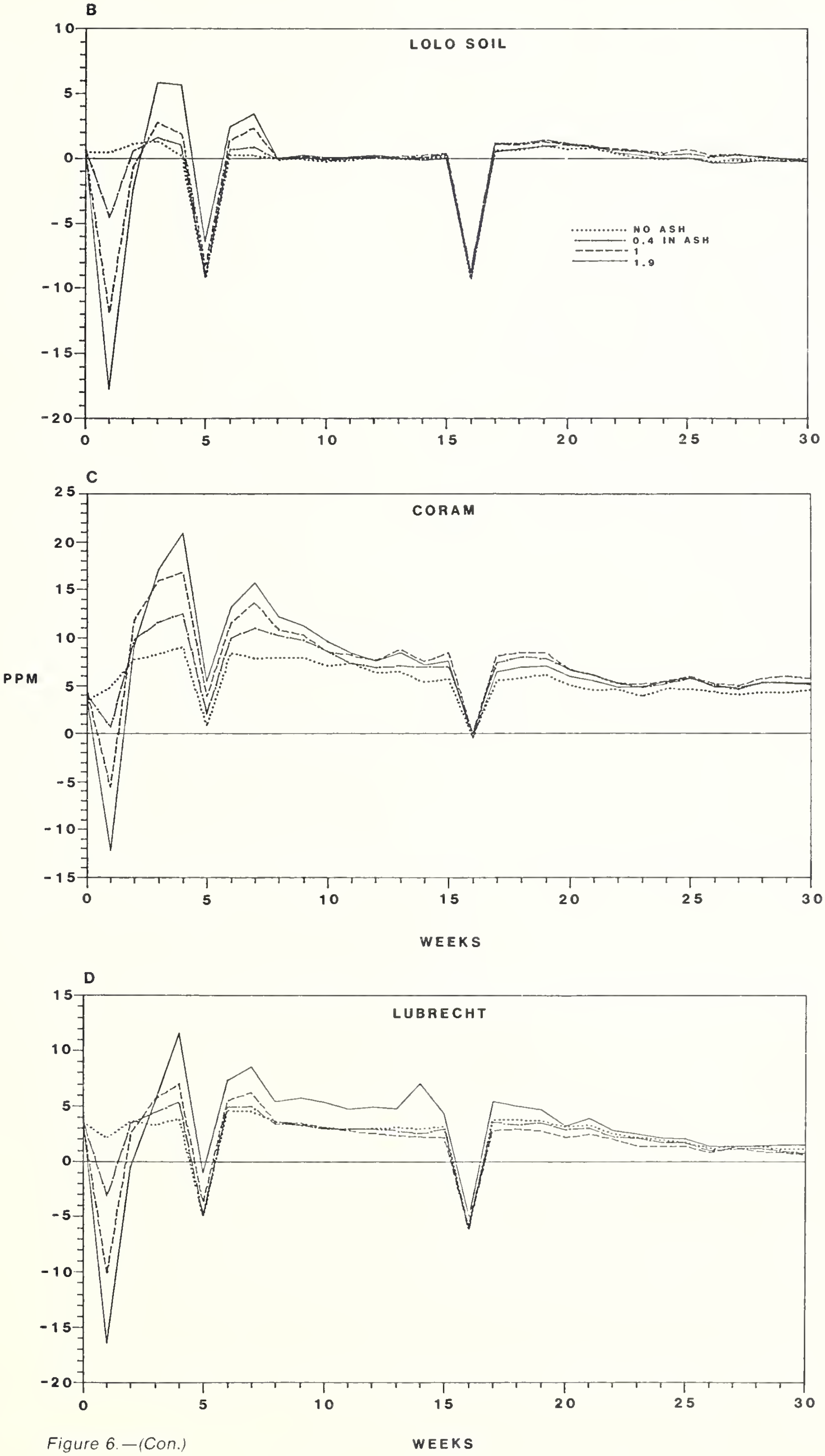
B
LOLO SOIL
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30
NO ASH
0.4 IN ASH
1
1.9
C
CORAM
25
20
15
10
5
0
-5
-10
-15
PPM
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30
WEEKS

Figure 6.—(Con.)

Sodium

The ash released the highest levels of sodium during the first 4 weeks of leaching, with steady, low releases throughout the rest of the study (fig. 7A).

Sodium losses were almost identical for all three soils (figs. 7B,C,D). This highly mobile ion was originally present in the three soils in similar concentration (42 to 58 µg/g) and so was expected to leach similarly under nearly identical leaching forces. The loss of Na from the ash and its storage by the soils during the first week was almost directly proportional to the Na in the ash. The controls stored almost no Na. With ash treatment all soils showed a short period of Na storage with low and almost steady loss thereafter. High Na storage by the nutrient-poor Lolo soil, to 110 µg/g for the 1.9-inch (5-cm) ash treatment, may have adversely affected the storage of other ions for this low exchange capacity soil.

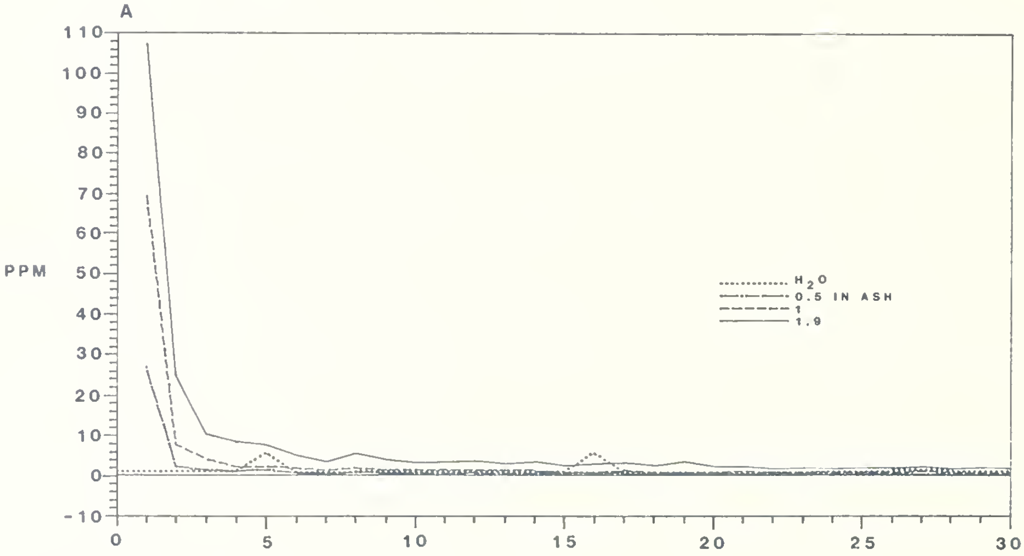

Figure 7.—Input of sodium from water and ash (A) and storage (−) and/or loss (+) of sodium from Lolo (B), Coram (C) and Lubrecht (D) soils as ppm.

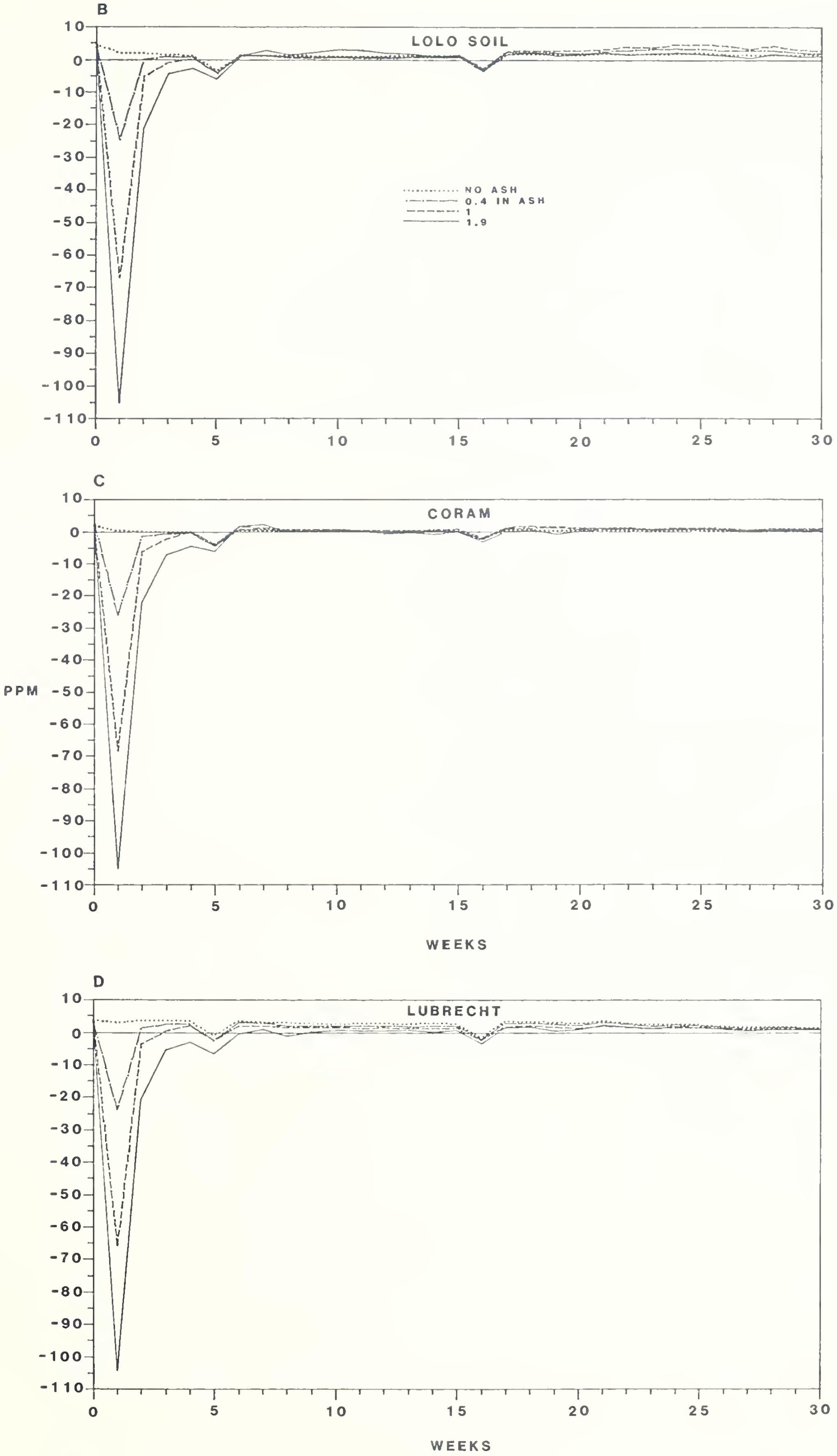
B
LOLO SOIL
NO ASH
0.4 IN ASH
1
1.9
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
5
10
15
20
25
30
C
CORAM
PPM
WEEKS
D
LUBRECHT
WEEKS

Figure 7.—(Con.)

Nitrate

Nitrate levels in the water varied considerably during the study, and nitrate release from ash was quite variable (fig. 8A).

Nitrate loss and retention for Lubrecht soils most closely resembled that of the Coram soils except that Lubrecht had initially high NO_3 (47 ppm). Both showed an accelerated loss near the end of the leaching cycle when soil temperatures were warmer (figs. 8B,C,D). Increased losses of NO_3 may be a reflection of increased nitrification or saturation of the anion exchange sites. Nitrate storage was generally low (12 ppm), the overriding pattern being one of NO_3 loss. Lolo soils lost and gained small amounts of NO_3 for the first 19 weeks (fig. 8B). As with the other soils, considerable NO_3 losses occurred from week 20 on.

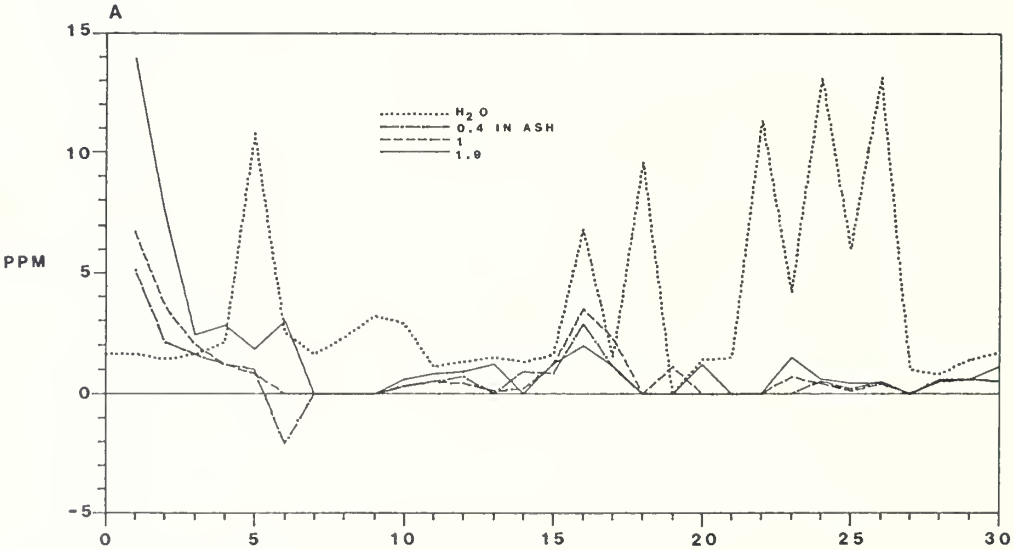

Figure 8.—Input of nitrate from water and ash (A) and storage (−) and/or loss (+) of nitrate from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

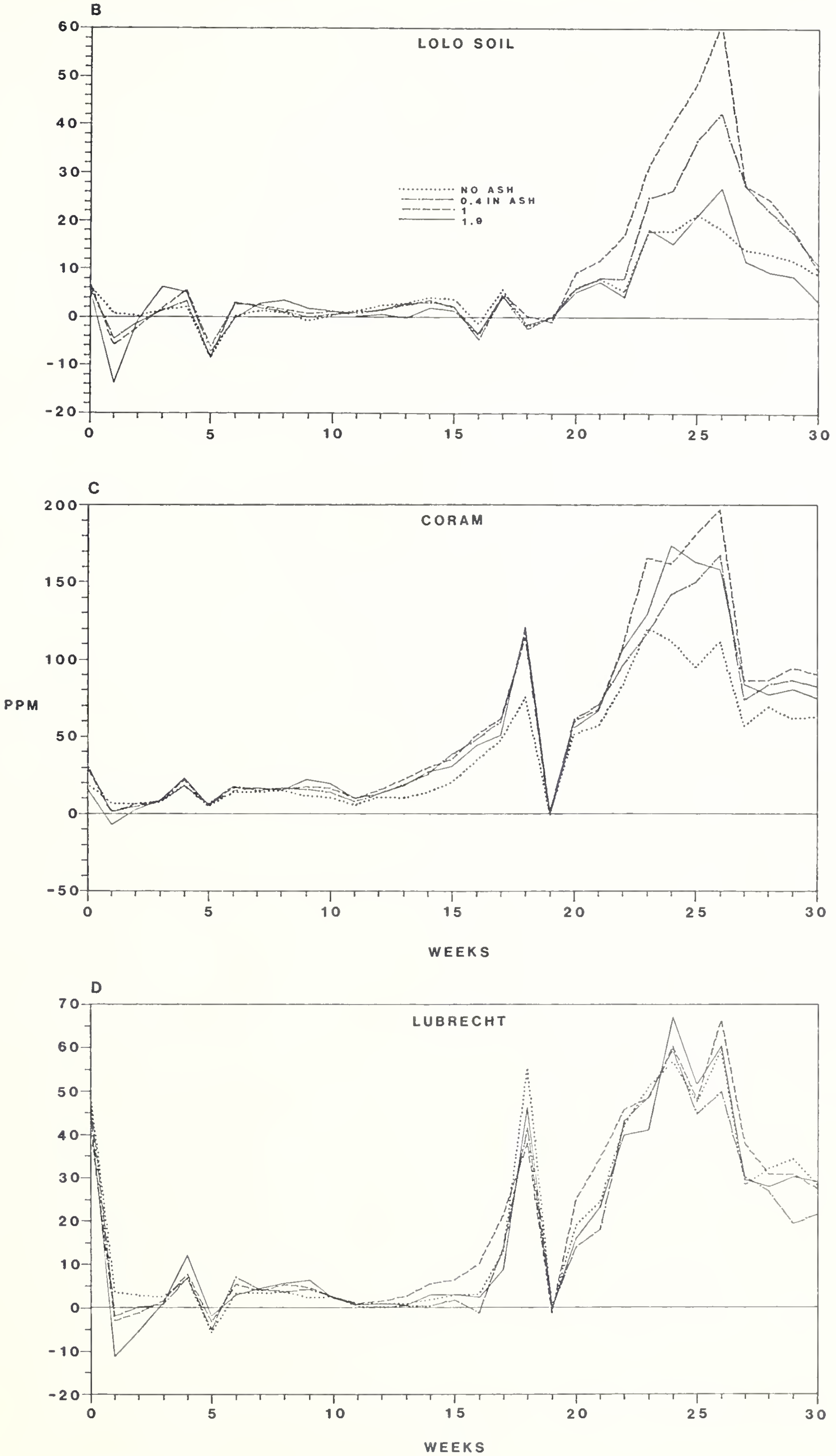
B
LOLO SOIL
60
50
40
30
20
10
0
-10
-20
NO ASH
0.4 IN ASH
1
1.9
0
5
10
15
20
25
30
C
CORAM
200
150
100
50
0
-50
PPM
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
70
60
50
40
30
20
10
0
-10
-20
0
5
10
15
20
25
30
WEEKS

Figure 8 —(Con.)

RESULTS BY SOIL TYPE

The following are research results on ion additions and loss by each of the three soils used in this study.

Lolo Soil (Dystric Eutrocrept)

This soil leached over 30 weeks lost Cu at the 0.4- to 1.9-inch (1- to 5-cm) ash depths, K and NO_3 at all ash depths (table 3). The control lost Na. Magnesium was stored by the Lolo soils, but calcium was lost only with the 0.4-inch depth of ash for all depths of ash applied. Potassium losses were significantly different between the 1- and 1.9-inch (2.5- and 5-cm) ash treatments (table 3). All treatments produced significantly different sodium and hydrogen levels in the leachate from this soil. Nitrate losses were higher in the 1-inch ash treatment, compared to the control and 0.4- and 1.9-inch treatments.

This nitrate-deficient soil failed to store any anions, suggesting a deficiency in anion exchange capacity. It tended to store other ions such as Ca and Mg that were initially low in the soil. Another study (Stark and others 1984) showed this soil to be severely nitrogen deficient. Ions added from ashfall would be unlikely to improve growth unless nitrate was added and retained.

Coram Soil (Cryocrept)

Calcium, copper, potassium, magnesium, and nitrate were lost from this soil as a result of leaching (table 3). Sodium and hydrogen ions were stored. The losses are probably the result of overloading of the cation exchange sites by water-soluble calcium mobilized during leaching. This flood of calcium would be expected to remove some ions on the exchange by mass action. Sodium and hydrogen are readily leached. These are thought to have been stored after the heaviest calcium mobilization had occurred. Most ash treatments produced ion levels that were significantly different from the control in this ion-rich soil.

A soil of this classification could be expected to lose some ions as a result of future ashfall. It would not be likely to increase in fertility unless scarce ions such as

Table 3.—Summary of significant differences between the means of net leachate ion concentrations (ppm) summed over 30 weeks of leaching versus ash depth within each soil. Determined by Duncan's MRT or LSD methods at 0.05 significance level[1]

Ion	Ash depth			
	1.9 inches	1.0 inch	0.4 inch	No ash[2]
		Lolo Soil		
[2,5]Ca	-163 a	-88 b	.59 c	[3]-52 c
Cu	.04 a	.12 b	.15 b	-1.09 c
K	57.0 a	70.4 b	71.7 b	93.1 c
Mg	-15.0 a	-11.1 a	-10.6 a	-11.3 a
Na	-97 a	-23 b	14 c	38 d
$H \times 10^{-7}M$	-7.9 a	6.1 b	4.9 c	14.9 d
[4]NO_3	188 ab	317 c	227 b	155 a
		Coram Soil		
[4,5]Ca	1,768 ab	1,882 a	1,733 bc	1,640 c
Cu	.18 a	.21 a	.28 b	-1.08 c
K	137 ab	141 b	156 c	132 a
Mg	209 ab	225 b	190 a	160 c
Na	-150 a	-64 b	-24 c	4.1 d
$H \times 10^{-7}M$[1]	-18.1 a	-6.2 b	-5.8 c	2.0 d
[4]NO_3	1,634 a	1,628 a	1,468 a	1,223 b
		Lubrecht Soil		
[2]Ca	289 a	344 a	421 a	477 c
Cu	.27 a	.3 a	.3 a	-1.06 b
K	141 a	149 a	161 b	170 b
Mg	47.5	53.8	64.9	69.2
Na	145 a	-38 b	31 b	74 c
$H \times 10^{-7}M$	-15.5 a	-3.1 b	-4.0 c	3.4 d
NO_3	666 a	469 b	519 ab	558 ab

---

[1] Both methods were used to test data. Results presented are Duncan results unless the two methods disagreed and sizes were unequal, in which case LSD was preferred.

[2] Any two values on the same line for an ion that are not accompanied by the same letter are significantly different, 0.05 significance level.

[3] A positive leachate concentration indicates a net loss of that ion from the soil column, a negative value indicates net storage.

[4] Multiple range tests not valid due to nonhomogeneity of variances, differences indicated are by two-tailed t-test at p = 0.05 level.

[5] Two groups within a line are significantly different at the 0.05 level if they do not share a common letter.

Zn were stored from the ash. Although proof is lacking, there is reason to believe that the ash adds exchange capacity to soils, possibly in the form of small particles that migrate downward under leaching pressure and hold trace elements.

Lubrecht Soil (Typic Eutroboralf, Frigid)

The Lubrecht soil was the most fertile and stored only Na in the 1- and 1.9-inch (2.5- and 5-cm) ash treatments and hydrogen at all ash depths (table 3). Small amounts of Cu were stored from the water by the control soil. Lubrecht soils lost less Ca, Mg, and NO_3 than did the calcium-rich Coram soil. The control lost the most K and Na, suggesting that the ash may add some exchange capacity. The loss of nitrate again suggests the high mobility of this ion and possible low anion storage.

Clearly, many ion interactions are occurring that cannot be explained by our current state of knowledge. The Typic Cryoboralf studied here appeared not to improve significantly in fertility from the application of ash.

Ion Loss and Storage Trends in Soils

The ions that were significantly different in the soil extract were not necessarily the same ions that were significantly different in the soil leachate. Soil extraction and ash leaching produced quite different ion concentrations by ash depth within a soil (tables 3, 4). Calcium, for example, was significantly different among ash depths in the leachate from Lolo soils—except 0.4 inch (1 cm) and the control—but not among the soil extractions after leaching was completed. One explanation may be the difference in extracting power of water and ammonium acetate. The calcium in the Coram leachate showed differences between the 0.4- and 1-inch (1- and 2.5-cm) ash depths, but calcium levels were different in soil extracts from Coram soil for all ash depths and the controls. If the two extractants, water and ammonium acetate, worked with similar extraction energies, then we would expect the Lolo soil to store calcium and the leachate to be little different in calcium content. This is close to what did occur. Differences in calcium concentrations in the leachate were related to ash depth for Lolo soil; more ash produced greater storage. These levels of storage over 30 weeks were low (52 to 163 ppm). The Lolo soil extracts were not able to reflect this low storage level. Some calcium added from ash and water may be,complexed in a form not easily extracted by ammonium acetate. In the case of the Coram soil, massive amounts (1,640 to 1,882 ppm) of calcium were lost from the soil in the leachate (table 4), but the ammonium acetate extraction after 30 weeks of leaching removed significantly different amounts of calcium from soil subjected to each ash treatment and the control. Ammonium acetate extraction of the Lubrecht soil removed significantly different levels of calcium from only the 1.9-inch (2.5-cm) ash treated and control soils (table 4).

Potassium was lost from all three soils in nearly equal amounts, yet the ammonium acetate extraction of the three soils produced not only different levels of K among soils, but some significant differences in K levels between treatments within each soil. It must be remembered that the soils used from each area were in truckload quantities. Because complete homogenization of such large volumes of soil is difficult to accomplish,

Table 4.—Summary of significant differences between the means of ammonium acetate extractable ions after 30 weeks of leaching versus ash depth within each soil

	Ash depth			
Ion	1.9 inches	1.0 inch	0.4 inch	0
	μg/g or ppm			
	Lolo Soil			
Ca	596 a	589 a	596 a	601 a
Cu	.64 a	.37 a	.79 a	.59 a
K	104.7 ab	105.1 ab	110.3 a	100.9 b
Mg	108.3 a	101.4 b	102.9 ab	106.2 ab
Na	37.3 a	34.4 ab	60.9 c	47.0 bc
	Coram Soil			
Ca	8,526 a	8,474 b	8,324 c	8,259 d
Cu	1.40 a	1.39 a	.71 b	.76 b
K	275.2 a	273.7 a	27.7 ab	285.8 b
Mg	276.5 a	276.2 a	279.5 ab	281.9 b
Na	54.0 a	43.7 a	46.1 a	40.9 a
	Lubrecht Soil			
Ca	3,520 a	3,470 ab	3,505 ab	3,460 b
Cu	.32 a	.46 a	.45 a	.30 a
K	1,187 a	1,153 b	1,172 c	1,158 bc
Mg	476 a	478 a	491 b	494 b
Na	100.5 a	93.7 b	88.2 c	87.3 c

some lack of homogeneity is still a possibility. Even sodium, which is highly mobile, did not show parallel differences in the leachate and soil extractions.

The levels of ions in the soil leachate from simulated rain water reflect more accurately what is occurring in the soil than does the more artificial ammonium acetate extraction of soils. These results have stimulated further research in this laboratory on the influence of soil extractants on forest soils and the relation of extracts to what is available to trees. The growth response of the seedlings with ash (see following section) except for the 1.9-inch ash treatment suggests that the ions were actually stored. The ammonium acetate extraction is not sensitive enough to show the low ion differences in most cases.

Bioassay of Leached Soils with Lettuce

To determine by short-term bioassay if the soil had improved in productive capability as a result of the ash, Simpson's black-seeded lettuce was grown in the soil tubes after the 30 leaching tests were completed. Results show the greatest dry biomass for lettuce grown on Lubrecht soils (table 5). For all soils except Lubrecht, the control had the lowest biomass. Ion additions from 0.4 and 1 inch (1 and 2.5 cm) of ash increased lettuce biomass by about 100 percent over the lower level for Coram soils, but by only 35 percent for the Lolo soils. Lettuce grown on the Lubrecht soil with 1 inch of ash added weighed the same as lettuce grown on the control soil, while that grown with 0.4 inch of ash actually showed reduced lettuce weight. This suggests a net loss of some essential ions from the Lubrecht soils when 0.4 inch of ash was added, or possible complexing of these ions in the soil in unavailable form. Lubrecht soils did show considerable losses of ions, especially NO_3. Perhaps the ash did not significantly increase the growth of lettuce on Lubrecht soils because they were initially quite fertile. The 0.4- and 1-inch ash additions produced small but statistically insignificant increases in lettuce weight on infertile Lolo soils (table 5).

For all soils, the 1.9-inch (5-cm) ash addition reduced the dry weight of lettuce over that of the 1.0-inch ash treatment, and for the fertile Lubrecht soil and infertile Lolo soil, below the weight achieved on the control soils. This suggests that 1.9 inches of ash may have created poor surface aeration because it was observed that this depth tended to pack with watering, whereas the lighter treatments generally became mixed with the litter as a result of watering. Ash accumulations of over 1.9 inches are not likely to improve fertility of most soils in the immediate future (based on greenhouse tests).

Table 5.—Dry weights of lettuce grown with three soils and three depths of volcanic ash (Mount St. Helens, collected from Moses Lake)

Location	Treatment	No ash control	0.4 inch	1.0 inch	1.9 inches
Coram	X	0.27	0.58	1.22	0.80
per plant	SD	.13	.29	.61	.40
Lolo Pass	X	.33	.49	.41	.13
	SD	.17	.25	.20	.07
Lubrecht	X	2.53	1.94	2.57	.61
	SD	1.26	.97	1.28	.30

The lettuce plants did not show clearly recognizable deficiency or toxicity symptoms according to the key of English and Maynard (1978), but the type of chlorosis suggested possible sulfur deficiency. Nishimoto and others (1977) found that lettuce made its maximum growth with 0.3 ppm P in solution. Based on the P present in the soil leachate, there should have been adequate P present to grow lettuce. Portions of the plants were not analyzed separately, but Berry (1971) found much more Zn in the petioles than in the leaf blades of lettuce. Berry and others (1981) analyzed Grand Rapids lettuce for 20 elements using controlled growth conditions and five different analysts. Comparisons between the nutrient content of two varieties are not warranted, but these are the only comparisons that are possible. In general, the levels of ions in the two varieties of lettuce are similar.

Tree Seedling Growth on Two Soils

Seeds of ponderosa pine, Douglas-fir, western larch, and lodgepole pine were planted in tubes filled with soil and ash applied at the three depths used in the leaching tests.

Results from the second year of growth were similar to those from the first year (data not included). Ponderosa pine seedlings on Lolo soils continued to grow better than on Lubrecht soils (fig. 9). Differences within treatments were not significant, except for the superior growth of ponderosa pine on the Lolo control soils. Douglas-fir on Lolo and Lubrecht soils showed no significant height differences within locations by ash depths or between locations. Lubrecht western larch remained taller than the Lolo western larch during the second

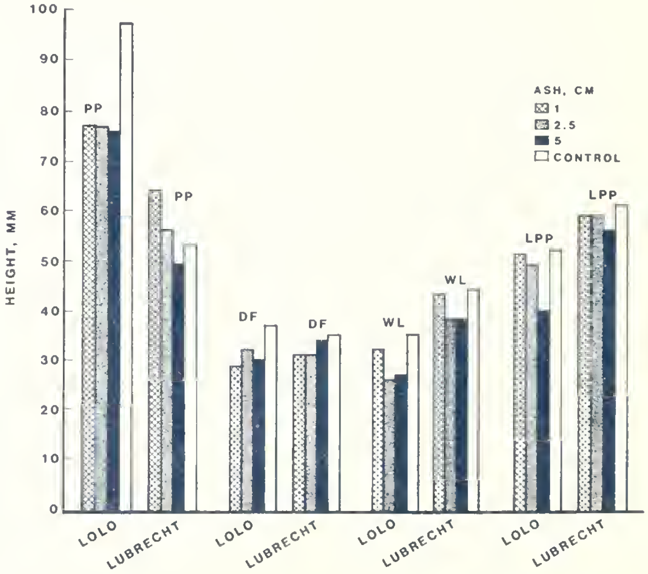

Figure 9.—Mean height of tree seedlings (mm) grown in two soils with three ash depths and control (no ash) for 2 years.

year, but the differences were not significant. Lodgepole pine grew slightly faster on the Lubrecht soil in the second year, compared to the Lolo soil. The 1.9-inch (5-cm) ash treatment continued to suppress growth in most cases (fig. 9).

Survival was best for Douglas-fir on the 1-inch (2.5-cm) ash treatment (90 percent) for the Lolo soil and for the control for western larch (100 percent). All lodgepole pines survived on the control and 0.4-inch (1-cm) ash treatments. Ponderosa pine survived best with the 1- and 1.9-inch (2.5- and 5-cm) ash treatments on the Lolo soil. Survival was poorer on the Lubrecht soils (50 to 100 percent). The 1-inch ash and control generally had good survival for most species.

APPLICATIONS

These results show that the 1 inch (2 cm) of ashfall in western Montana from the 1980 eruption at Mount St. Helens is not expected to significantly affect the fertility of the soils tested in Montana. This short-term study suggests that considerably more ash would have to fall to significantly improve soil fertility levels. The low-nutrient demanding species such as ponderosa pine on nutrient-poor soils may have benefitted slightly from the ashfall, but the results are probably not of sustained significance. If adequate ash fell to improve the chemistry of the poorest soils, adverse physical effects on the soil in respect to aeration and abrasion of vegetation could be expected, although soil water retention might be improved. More than 1.9 inches (5 cm) of ash in a single fallout is slightly detrimental to height growth of young potted tree seedlings, but a similar ash depth would not necessarily adversely affect native vegetation outside the greenhouse.

At present, management practices do not need to be altered to take advantage of the ashfall. Future ashfall of substantially over 1 inch (2.5 cm) may require improved scarification to mix the ash with soil at the time of planting or before seed fall. The impact of ashfall on the entire forest ecosystem cannot be projected from this study.

This study's most significant contribution is to point out areas of uncertainty in our understanding of ion release from ash and storage by different soils. More research on a wider range of soils and for an entire ecosystem is needed to develop a better understanding of nutrient dynamics in ash and soil. Future experiments need to answer specific questions raised by this research. Examples: Why is potassium lost from a soil that can store calcium and apparently has available cation exchange sites? Why do some soils lose nitrate so readily when this ion is usually low in concentration?

CONCLUSIONS

1. Three soils of different initial fertility responded differently to ash additions in the greenhouse in terms of ion storage and release. More extensive study is needed to find the reasons for the responses.
2. Based on the greenhouse results, the 1 inch (2.5 cm) of ashfall that occurred in western Montana in 1980 is not expected to significantly increase the short-term fertility of moderately fertile soils. More time for weathering and incorporation of the ash may show chemical and physical benefits not evident in this study. The inceptisol was too nitrogen deficient to benefit from the ash and could not capture significant amounts of nitrate.
3. Volcanic ash has the ability to remove copper from incoming water and to store this ion. Presumably ash would also remove copper from rainfall.
4. Under greenhouse conditions in the absence of plant uptake, ash does not weather rapidly enough to improve soil fertility for trees after an equivalent of 3 years of leaching as assayed by tree seedling height growth (no data are available on mineralization of the litter). Deeper levels of ash may be detrimental to seedling height growth in the greenhouse.
5. Soils high in calcium and magnesium lost these ions while those low in calcium and magnesium stored these ions. Soil with intermediate calcium levels stored small amounts of calcium.
6. All three soils lost K and NO_3. These losses could influence growth, particularly the K and NO_3. However, less was lost with greater ash depths.
7. Periods of high ion additions in the tap water showed that the exchange sites in the Lolo and Lubrecht soils were not saturated, even though the calculation of base saturation showed them to be saturated. Ammonium acetate solubilizes calcium and magnesium that is not stored on the exchange sites.
8. Under greenhouse conditions, the dry weights of lettuce grown in the three soils with ash added showed improved growth in the short term on the Coram soil, but not on the Lubrecht soil. Ash did not significantly increase growth on the Lolo soil. With 1.9 inches (5 cm) of ash on the soil surface, the growth of lettuce on all three soils was reduced, probably from altered aeration and drainage.
9. No significant height growth differences occurred in seedlings grown on Lolo or Lubrecht soils with ash for ponderosa pine or Douglas-fir. Western larch growth on both soils was extremely poor, but poorest on the nutrient-deficient Lolo soil.
10. At present, management practices do not need to be altered to take advantage of the last ashfall.

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Stark, Nellie M.; Essig, Don A. Nutrient release from Mount St. Helens volcanic ash and retention by western Montana soil. Research Paper INT-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 22 p.

Three western Montana soils of varying fertility and physical characteristics were placed in large tubes, covered by different depths of volcanic ash from Mount St. Helens eruption to test the release of ions from ash and ion storage or loss from the soil. The ion concentration differences between water added and water lost from the soil were used to show net ion storage or loss from the soil. Lettuce and conifer seedlings were grown in the leached soils to estimate the influence of ash on growth. The three soils responded to ion additions differently. Ash improved lettuce growth for only the calcareous soil. Of the four conifers tested, only ponderosa pine seedlings on the poorest soil showed improved growth with ash the first year. Most growth differences were not significant.

KEYWORDS: ash leaching, Mount St. Helens, nutrient storage, soils, volcanic ash

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10529

United States
Department of
Agriculture

Forest Service

Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401

Research Paper
INT-339

April 1985

Pinyon-Juniper Volume Equations for the Central Rocky Mountain States

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ACKNOWLEDGMENTS

Many individuals contributed to this interagency effort in the organizational, field, and data entry phases. Participants were from the U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management and Bureau of Indian Affairs; Colorado State Forest Service; and Nevada Division of Forestry. Unfortunately, I was not able to meet many of those who had key roles in this study—I only saw the data. However, I would like to mention the Nevada BLM district foresters who helped me get a field perspective on pinyon-juniper woodlands: Jack Matuska (Battle Mountain), Mike McGinty (Carson City), John McGlothlin (formerly Ely, presently Burns, OR, BLM), Harry Rhea (Ely), and Skip Ritter (Elko).

RESEARCH SUMMARY

Gross cubic foot volume equations are now available for pinyon-juniper and several other woodland species in Nevada, Idaho, Utah, Colorado, Wyoming, and South Dakota. The volume equations are based on data collected as a subsample of woodland inventories conducted by Federal and State land management agencies. In these inventories, volumes of 4,705 trees were estimated by a visual sampling method.

Use of the equations requires measurement of a tree's diameter at the root collar (DRC), total height, and number of basal stems. Thirteen equations, applicable to different parts of a species' range, are presented for Utah juniper, western juniper, Rocky Mountain juniper, oneseed juniper, singleleaf pinyon, pinyon, Gambel oak, bur oak, mountain-mahogany, and a group of woodland hardwoods.

A test of several equations against some local volume data revealed prediction errors up to 20 percent or more in half the cases. However, the equations should be adequate for use in large State-wide woodland inventories.

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Cover Photo: Over looking the main fork of Elk Creek near New Castle, CO.

Pinyon-Juniper Volume Equations for the Central Rocky Mountain States

David C. Chojnacky

INTRODUCTION

Pinyon-juniper woodlands have a rich history of use. Native Americans in the West depended on the trees for fuel wood and food. In the late 1800's settlers cut an undocumented amount of pinyon (piñon) and juniper trees for lumber, mine props, fuel wood, charcoal, fenceposts, and other products for mining and ranching enterprises. However, during the past 40 to 50 years, the vast acreages of pinyon-juniper (P-J) woodlands were virtually ignored as a source of wood. In many areas, P-J removal by chaining was the accepted management practice for improving the land's grazing potential.

Today, P-J woodlands again are being eyed as a valuable resource for fuel wood and other uses. Increased energy demands and new requirements for sound ecological land management are creating new pressures and opportunities on approximately 48 million acres of P-J woodlands in the Western United States.

This concern prompted a joint effort by the U.S. Department of Agriculture's Forest Service (Forest Survey), the Department of the Interior's Bureau of Land Management and Bureau of Indian Affairs, and several State forestry departments to inventory P-J woodlands in Nevada, Idaho, Utah, Colorado, South Dakota, and Wyoming. Data provided by this joint inventory were the basis for the study described in this paper. This study's purpose was to develop individual tree cubic foot volume equations for pinyon, juniper, and other woodland tree species sampled by these inventories.

REVIEW OF PAST WORK

Constructing volume equations for pinyon and juniper trees presents unique problems. Unlike most conifers, excessive branching and multiple basal stems appear to be normal growth patterns for P-J. Researchers have tried a variety of measurements to describe P-J trees' bushy character, usually including crown and stem variables in their volume equations in addition to conventional variables of diameter and height.

Howell (1940) and Reveal (1944) conducted some of the first P-J volume studies in Arizona, New Mexico, and Nevada (summarized by Barger and Ffolliott in 1972). This work became P-J volume inventory standards used in Soil Conservation Service handbooks. These volume tables required measurement of diameter at breast height (d.b.h.), crown diameter, diameter of the tallest stem at 1 foot, and the amount of 4-foot wood segments at least 2 inches in diameter.

Mason and Hutchings (1967) offered tree foliage yield models based on crown dimensions for juniper in Utah. Storey (1969) constructed equations for predicting P-J biomass in southern California from measurements of crown dimensions, total height, and basal diameter at 1 foot above ground line. Estola (1979) developed P-J volume equations for southern Colorado and northern New Mexico using diameter at 1 foot above ground line, crown diameter, and total height as predictor variables. Also, in northern New Mexico, Clendenen (1979) developed P-J volume equations using diameter at the root collar (DRC), total height, and number of stems 3 inches in diameter within 1 foot above ground line. Gholz (1980) reported volume and biomass equations for juniper in western Oregon using only basal circumference of the stem as a predictor variable.

Tausch (1980) studied allometric relationships between plant parts for P-J in southwestern Utah. He did not provide volume equations but gave biological reasons for expecting P-J volume to be proportional to a function of DRC. He suggested the proportionality constant between volume and DRC would change with site quality. Miller and others (1981) and Meeuwig and Budy (1981) presented two ways for estimating P-J biomass for the same areas in Nevada. Their equations required measurement of crown diameter, d.b.h., number of stems greater than 3 inches, and diameter at 1 foot above ground line.

Weaver and Lund (1982) examined diameter-weight relationships for juniper in eastern Montana. Their results undermined Tausch's site-quality hypothesis by finding the same proportionality constant between tree weight and DRC on three different sites. Chittester and MacLean (1984) built an equation for estimating volume from d.b.h. and height for juniper in Oregon and California.

Ambrosia and others (1983) used pinyon and juniper volume equations in a Nevada Landsat study. Although they gave no reference source, these equations were identical to preliminary equations developed by Chojnacky (1981) for interim use in Nevada prior to this publication. These equations required DRC and total height measurements and were based on data described by Born and Chojnacky (in preparation).

Past work can be summarized by observing that everyone has measured pinyon and juniper differently. Only Tausch and Weaver gave biological reasoning for their work. The rest cited statistics associated with regression modeling as justification for their particular equation. The early work of Howell and Reveal was perhaps the most unique in that the number of 4-foot wood segments was used as a predictor variable. Some form of diameter measurement of the main stem was almost a unanimous choice for a predictor variable, but the exact place of this measurement has been a point of debate. Unfortunately, any direct comparison of all the P-J volume and biomass models would be futile unless a specific study were designed to take all the different measurements on the same P-J trees. Also, different standards were used for the minimum diameter of branch material included in the volume and biomass equations.

This study resulted from efforts in multiagency cooperation required by 1970's "environmental era" legislation. Its design mimicked that used by Clendenen (1979) in New Mexico. Because the study was closely linked to on-going inventories, it was not possible to carefully test past work or propose new ways to estimate pinyon-juniper volume. Instead, a few simple measurements—basal diameter, crown dimensions, total height, and number of stems—important in past work were made on a random subsample of all trees inventoried. This paper describes the search for the best volume equations from the data provided by the multiagency pinyon-juniper inventories.

DATA COLLECTION

Data were collected for P-J trees in Nevada, Idaho, Utah, Colorado, South Dakota, and Wyoming (figs. 8-11 in appendix A). The data also included some mountain-mahogany, oak, and other hardwood species found in the woodland types. Table 5 in appendix A contains a summary of the data collected by species and area. Quantiles of key variables and percentage of single stems are listed to illustrate the diversity of the data from the sample areas.

The trees were selected as a subsample of an inventory using 0.1-acre plots located on a 5 000 m grid (sometimes 2 500 or 10 000 m). Individual trees were sampled by diameter size class and species on each plot. At most, three trees of each species were selected in the diameter classes of 3 to 9.9 inches, 10 to 17.9 inches, and greater than 18 inches. Measurements recorded for each tree were diameter at root collar (DRC), total height (HT), maximum (CRMX) and minimum (CRMN) crown diameter, and number of stems (STEMS) 3 inches and larger within the first foot above DRC. If a tree forked at the ground line, an equivalent DRC (EDRC) was computed from the DRC of each fork:

$$\mathrm{EDRC} = \sqrt{\mathrm{DRC}_1^2+\mathrm{DRC}_2^2+\mathrm{DRC}_3^2+\ldots}$$

A gross volume that included bark, wood, and dead branches (from ground line to 1.5-inch minimum branch diameters) was estimated for each tree by a visual technique. This volume estimate was obtained by visually classifying each stem and branch segment into a 2-inch by 2-foot class. Huber's formula was used to compute the volume of each segment. Segment volumes were then summed to obtain the volume of each tree.

The technique, called visual segmentation, has proved an adequate base for constructing volume equations. Born and Chojnacky (in preparation) compared volume equations built from visual estimates to actual volume measurements of destructively sampled trees. The equations using visual estimates predicted mean volume per acre within 0 to −9 percent of the actual measurements.

In theory, visual volume estimation should only result in random error among all the volume estimates. Random error measurements for a dependent variable (in this case the visual volume) present no difficulties when developing volume equations by regression (Neter and Wasserman 1974, p. 167). The consistent negative error found in the field test of visual volume estimation indicated a discrepancy between theory and practice, but not enough to justify increasing field sampling costs 10 to 20 times by felling trees to measure actual dimensions of each volume segment.

All field procedures used in this study were from manuals used by the USDA Forest Service, Forest Survey Unit in Ogden, UT (USDA 1983). All field personnel involved in the study used the same manuals, but it was not possible to uniformly monitor quality control for all agencies and all crews.

DATA ANALYSIS

The volume modeling process involved four steps: (1) identifying important predictor variables, (2) choosing an equation form, (3) selecting the number of equations, and (4) determining the reliability of the equations. Before any analysis was done, data were grouped by species into two large geographic areas. This was done at the request of the study designers. Nevada, Idaho, and Utah (west of the Wasatch, Parvant, and Tushar Mountains) were called the Great Basin States. Colorado, Wyoming, and the remainder of Utah were called the Colorado Plateau States. These two areas roughly corresponded to the geographic ranges of the two species of pinyon represented in the data (see fig. 9, appendix A). Collectively, the entire area was referred to as the central Rocky Mountain States. All analyses were done using the Statistical Analysis System (SAS) software package (SAS 1982).

Important Predictor Variables

Of all the variables available to predict volume, DRC is probably most important. All previous researchers used some type of diameter measurement in their volume and biomass equations. Tausch (1980) and Weaver and Lund (1982) also gave biological support to the hypothesis that a function of DRC is proportional to stem wood (although the two differ on the exact meaning of the proportionality constant in this relationship). Figure 1 shows the relationship between DRC and volume. This figure supported findings of past researchers on the importance of DRC and was characteristic of all P-J data available for this study.

An attempt was made to explain the variability (observed in fig. 1) in the DRC-volume relationship for all data groups listed in table 5 in appendix A. The additional variables, HT, CRMX, CRMN, and STEMS, were

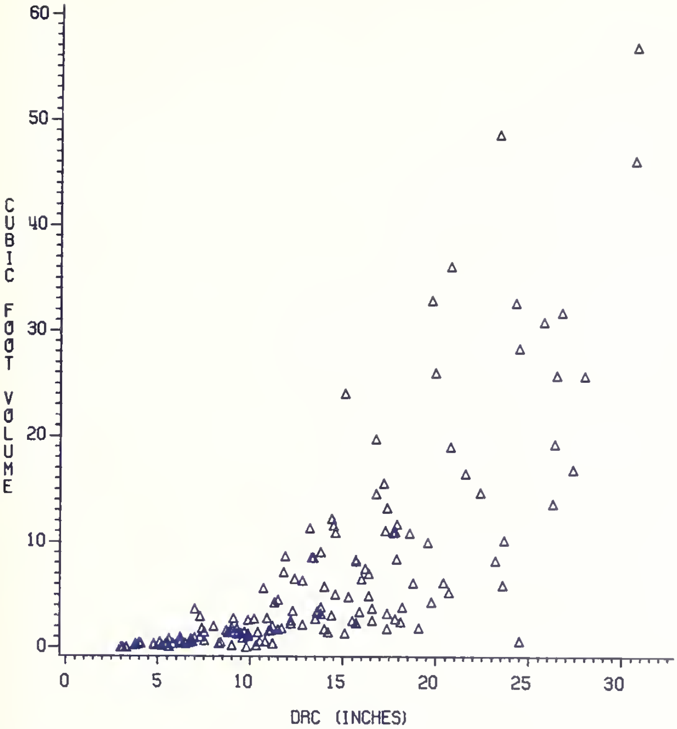

Figure 1.—Volume plotted against DRC for Utah juniper trees from the Moab BLM District.

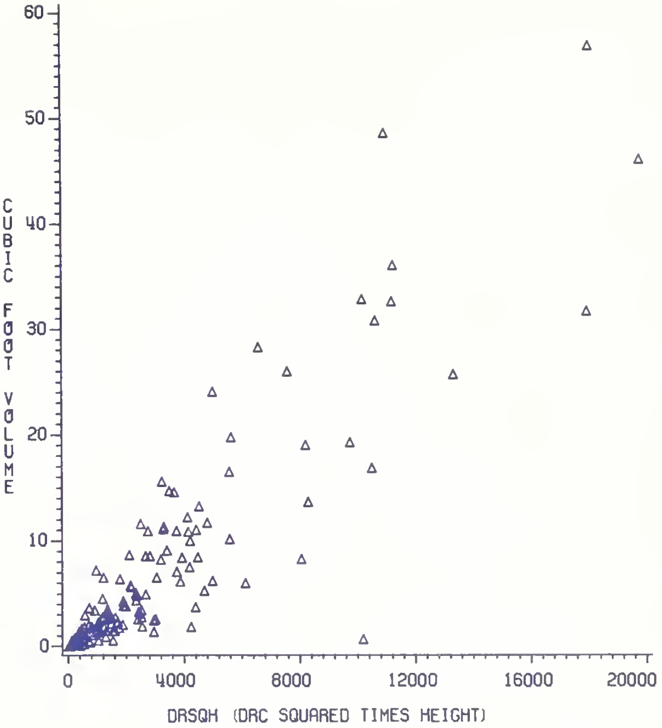

Figure 2.—Volume plotted against DRSQH for Utah juniper trees from the Moab BLM District.

analyzed in exploratory plots, multiple regressions, and stepwise regressions. Some benefit in volume predictions resulted from adding HT and STEMS into the volume prediction model, but most of the variability in the DRC-volume relationship could not be explained. The crown variables seemed to add very little to the volume prediction model, when DRC was already in the model. The DRC and HT variables were combined into a simple variable, DRSQH, by multiplying DRC squared times HT. A diameter and height combination variable that predicts volume well for commercial timber species worked as well for P-J. The STEMS variable was rendered almost useless because of an apparent interaction between stem sizes (not measured) and number of stems for a given P-J tree. However, it helped volume predictions somewhat to use a dummy variable to indicate whether a tree was multiple-stem or single-stem.

Equation Form

Modeling the DRSQH to volume relationship as a simple linear equation would be desirable for field use, but there were problems with this choice as illustrated in figure 2. Moab juniper data show the variance of volume increasing with tree size. This created a problem because the few largest trees disproportionately dominated the outcome of regression coefficient estimation.

The log transformation is commonly used to deal with increasing variance problems in regression. This transformation rescales data so that small and large trees have the same impact upon estimation of the regression coefficients. Transforming by applying fractional powers (such as $X^{1/4}$, $X^{1/3}$, $X^{1/2}$, and so forth) will also accomplish the same purpose as the log transformation. After examining several transformations on a subset of the data, the log and cube root transformations were selected for comparison on all data.

Figures 3 and 4 demonstrate the effect of the log and cube root transformations on the Moab juniper data. The log transformation appeared to compress the data too much for large trees, actually decreasing the variance with increasing tree size. The cube root transformation looked more reasonable.

All data for the other species from other areas responded to the transformations the same way the Moab data did. Additional plots of DRSQH against volume with stem counts overlaid showed some gain from inclusion of a dummy variable to distinquish single- from multiple-stem trees. Therefore, the final equation form selected for regression estimation of the coefficients was:

$$V_i^{1/3} = a + b(DRSQH_i)^{1/3} + c(STEM_i) + \epsilon_i \qquad (1)$$

where

V_i = visually estimated cubic foot volume to 1.5-inch minimum branch diameter (includes live wood, dead wood, and bark) of the ith tree

$DRSQH_i$ = DRC squared times total height of the ith tree

$STEM_i$ = 1 if a single-stem; 0 if a multiple-stem of the ith tree

a, b, c = coefficients to be estimated by regression

ϵ_i = random error (assumed to be zero on the average) of the ith tree.

During the analysis, I uncovered evidence for questioning the quality of some of the visual volume data.

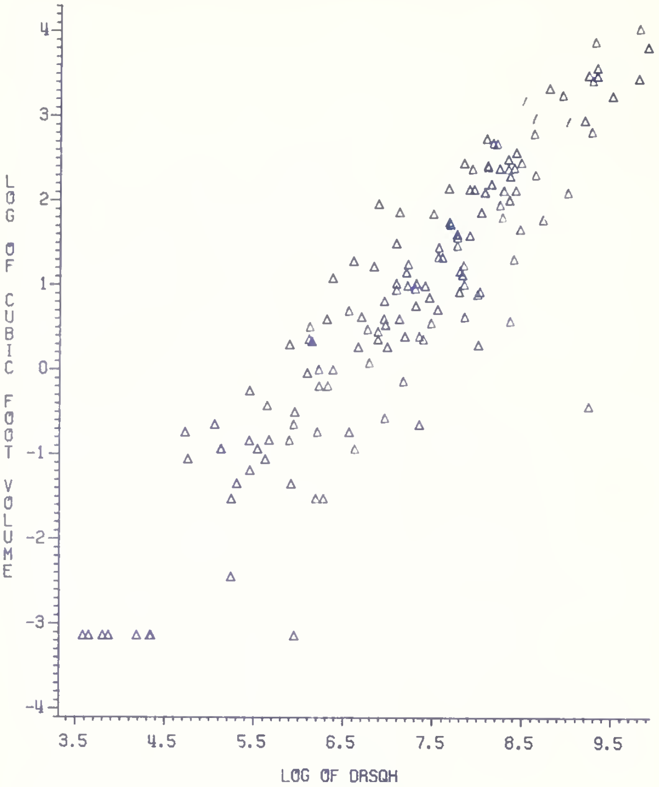

Figure 3.—Log transformation of volume plotted against DRSQH for Utah juniper trees from the Moab BLM District.

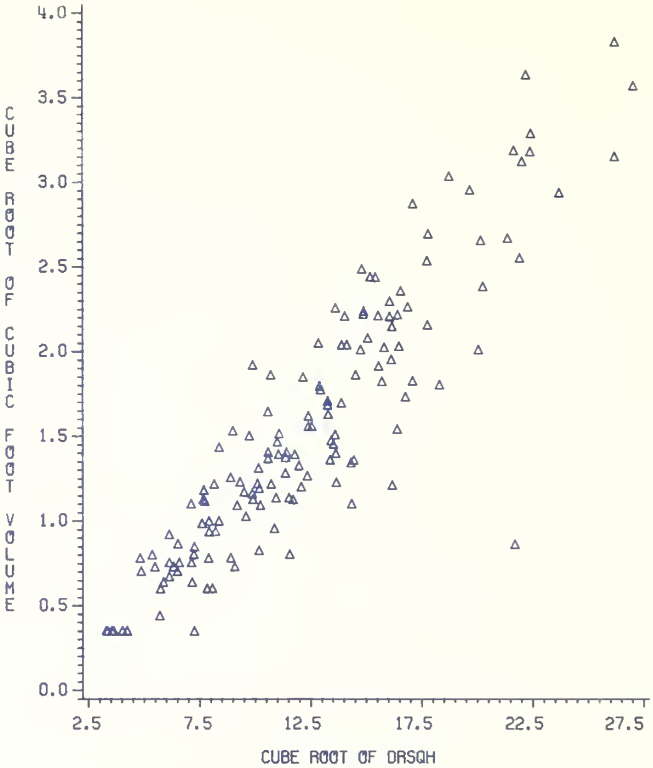

Figure 4.—Cube root transformation of volume plotted against DRSQH for Utah juniper trees from the Moab BLM District.

Rather than discard data or conduct a multiagency edit, I used a weighted regression method to minimize the effect of those data points that fell far from the regression line. The observations were weighted in regression by the following biweight function (Mosteller and Tukey 1977):

$$w_i = \begin{cases} (1-u_i^2)^2, & |u_i| \le 1 \\ 0, & \text{elsewhere} \end{cases} \qquad (2)$$

with

$$u_i = (V_i - \hat{V}_i)/6M$$

where

w_i = biweight of the ith tree

V_i = visually estimated volume of the ith tree

$\hat{V}_i$ = predicted volume from the regression of the ith tree

M = the median of all $(V_i - \hat{V}_i)$ quantities (that is, the median residual from a regression).

Figure 5 illustrates the effects of biweight function on the residuals for Utah juniper from the Ely BLM District. The outlying data points are clearly minimized in this figure. However, the effect of the biweight function on parameter estimation was less dramatic. For example, the parameter estimates (in eq. 1) for the Ely data were $a = -0.036033$, $b = 0.135638$, and $c = -0.018677$ before biweighting and $a = -0.036549$, $b = 0.135689$, and $c = -0.018476$ after biweighting.

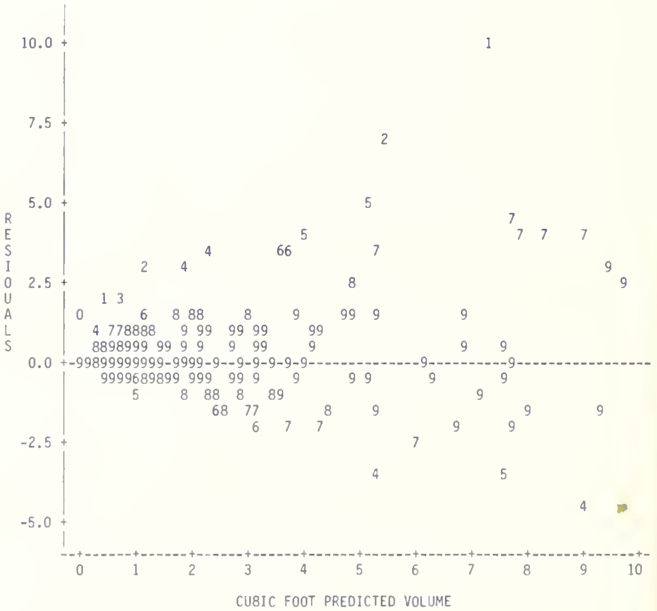

Figure 5.—A residual plot from a biweight regression of Utah juniper from the Ely BLM District. The numbers represent the percent of each observation used in the biweight regression: 0=0 to 4 percent, 1=5 to 14 percent...9=85 to 100 percent.

Number of Equations

Data were available for developing 33 volume equations, if each species from each area were kept separate. Combining some of these data sets was a difficult task because few good statistical methods exist for objective grouping. My approach used statistical tests between groups of regression coefficients and comparative plotting of regression equations.

Graybill (1976, p. 247) presented theory for testing whether or not a set of regression coefficients are similar. But, for the event of dissimilar coefficients in a set, Graybill gave no way to identify which coefficients are dissimilar. However, this approach was a good starting point.

The data were tested for full and reduced models for each species within the two large areas, the Great Basin States and Colorado Plateau States. A full model had a distinct set of regression coefficients for each BLM district or small area within the large area. A reduced model had only one set of coefficients for the entire large area.

Table 1 shows no significant difference between the full and reduced models for Utah juniper and pinyon in the Colorado Plateau States, and for western juniper in the Great Basin States. Data for these areas were grouped into their respective reduced models. Further analysis was done for those areas showing significant results in table 1. Graphs of the full models were examined to distinquish which areas should have separate volume equations.

Equations for the Great Basin States are shown in figures 6 and 7. The Utah juniper equations for the BLM districts of Ely, Elko, and Winnemucca (also

Table 1.—Analysis of variance tables comparing full and reduced volume models for pinyon and juniper

Source	Degrees of freedom	Sum of squares	Mean square	F-value	Prob > F
Utah Juniper in the Great Basin States					
Total	1,339	2,617.659			
Full model	24	2,573.803			
Reduced model	3	2,568.511			
Gain due to full model	21	5.292	0.2520	7.56	0.0001*
Error	1,315	43.856	.0334		
Utah Juniper in the Colorado Plateau States					
Total	397	892.891			
Full model	12	878.180			
Reduced model	3	877.799			
Gain due to full model	9	.381	.0423	1.11	.3544[ns]
Error	385	14.711	.0382		
Rocky Mountain Juniper in the Colorado Plateau States					
Total	194	359.158			
Full model	9	354.285			
Reduced model	3	353.088			
Gain due to full model	6	1.197	.1995	7.59	.0001*
Error	185	4.874	.0263		
Western Juniper in the Great Basin States					
Total	177	669.961			
Full model	6	663.288			
Reduced model	3	663.182			
Gain due to full model	3	.106	.0353	.91	.4375[ns]
Error	171	6.672	.0390		
Singleleaf Pinyon in the Great Basin States					
Total	1,445	2,931.848			
Full model	20	2,910.769			
Reduced model	3	2,909.535			
Gain due to full model	17	1.234	.0726	4.91	.0001*
Error	1,425	21.079	.0148		
Pinyon in the Colorado Plateau States					
Total	350	762.673			
Full model	12	753.441			
Reduced model	3	753.090			
Gain due to full model	9	.351	.0390	1.43	.1737[ns]
Error	338	9.232	.0273		

* This is the probability from an F-distribution (with degrees of freedom from the gain due to the full model and from the error) of getting a value larger than the reported F-value. For the α-level set at 0.05, these are significantly different.

[ns] For the α-level set at 0.05, the full and reduced models are not significantly different.

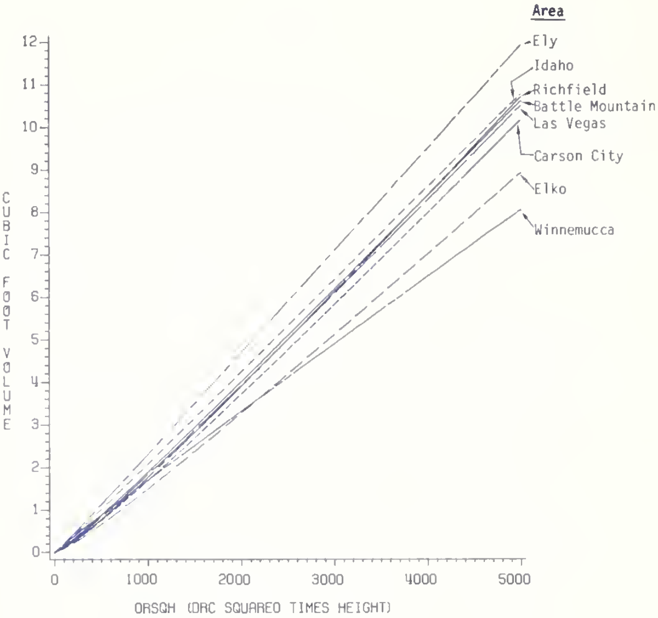

Figure 6.—Volume equations for multiple-stem Utah juniper in the Great Basin States. All area labels refer to BLM districts, except Idaho, which refers to southern Idaho.

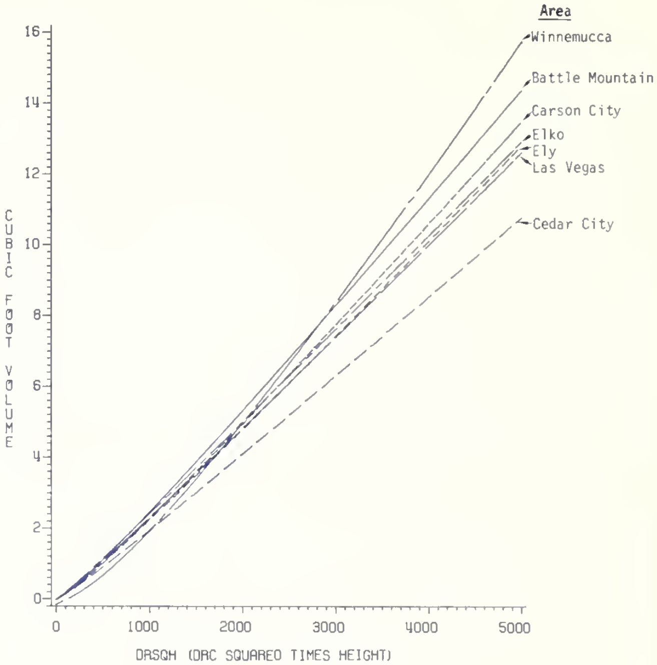

Figure 7.—Volume equations for single-stem singleleaf pinyon in the Great Basin States. The area labels refer to BLM districts.

includes Susanville BLM) looked different from the rest (fig. 6). I kept Ely and Winnemucca separate, but combined Elko with the rest of the Great Basin area. The Elko data contained a large percentage of single-stem trees, and in a graph of single-stem equations (not shown) the Elko data were not different. The Winnemucca and Cedar City singleleaf pinyon volume equations appeared distinct from the rest in figure 7. However, these differences were not meaningful because the Winnemucca data contained too few trees and the Cedar City data contained mostly small trees (DRSQH less than 2,000).

For the Colorado Plateau States, the table 1 results indicated further analysis for only Rocky Mountain juniper. Graphs of full models for Rocky Mountain juniper did show differences, but I combined all the data because of small sample sizes within groups.

The final number of P-J equations was based on the F-tests and on graphical analysis, as described for most of the data. In the case of mountain-mahogany, Rocky Mountain juniper, the oaks, and hardwoods, a small sample size dictated equations by species without consideration of geographic areas. Thirteen distinct volume equations were developed. A volume table for each equation is given in appendix B. Table 2 lists a guide for selecting a volume equation for each area and species.

Reliability of Equations

Additional statistical analysis should be done to examine reliability of regression equations when coefficients are estimated from transformed data, but equation predictions are retransformed for use. Such predictions are subject to transformation bias, and regression statistics in transformed units also can be misleading. I examined the bias of the cube root transformation, recomputed the R^2 statistic, and tested some of the volume equations against another data set. Duan (1983) presented a smearing estimator, a nonparametric retransformation method, that can be used to approximate the bias of any transformation. This was used to compute an approximate bias, defined as the difference between the predicted value from regression and the smearing estimator. The smearing estimator was calculated as:

$$SE = \frac{1}{n} \sum_{i=1}^{n} h(\underline{x}'\underline{\hat{\beta}} + w_i\hat{\epsilon}_i) \qquad (3)$$

where

SE = smearing estimator

$h(\cdot)$ = inverse of the transformation (the cubic function)

$\underline{x}$ = row vector of regression predictor variables

$\underline{\hat{\beta}}$ = vector of regression coefficients

$\hat{\epsilon}_i$ = residual from regression for the ith tree

w_i = biweight of the ith tree (eq. 2)

n = number of trees.

The transformation bias is listed in table 3 as a percentage for several quantiles of the sample data. Because this bias is always negative, the volume equation will underestimate by the amount of the biases. No attempt was made to correct for the transformation bias, because the bias was relatively small and a bias adjustment that varied according to tree size would be complicated to apply.

Table 2.—A guide for using woodland volume equations and tables in the central Rocky Mountain States

State	Species	Area of application	Volume equation coefficients[1]			Volume table number (in appendix B)
			a	b	c	
Colorado	Hardwoods[2]	entire State	−0.13822	0.121850	0	18
	Oneseed juniper	eastern Colorado	−.19321	.136101	0.038187	12
	Utah juniper	western Colorado	−.08728	.135420	−.019587	9
	Rocky Mountain juniper	entire State	.02434	.119106	0	11
	Pinyon	entire State	−.20296	.150283	.054178	14
	Gambel oak	entire State	−.13600	.145743	0	15
Idaho	Mountain-mahogany	southern Idaho	−.13363	.128222	.080208	17
	Hardwoods[2]	southern Idaho	−.13822	.121850	0	18
	Western juniper	southern Idaho	−.22048	.125468	.100092	10
	Utah juniper	southern Idaho	−.13386	.133726	.036329	6
	Rocky Mountain juniper	southern Idaho	.02434	.119106	0	11
	Singleleaf pinyon	southern Idaho[3]	−.14240	.148190	−.016712	13
Nevada	Mountain-mahogany	entire State	−.13363	.128222	.080208	17
	Western juniper	entire State	−.22048	.125468	.100092	10
	Utah juniper	Carson City, Battle Mountain, Elko, and Las Vegas[4]	−.13386	.133726	.036329	6
	Utah juniper	Ely[4]	−.03655	.135689	−.018476	7
	Utah juniper	Winnemucca and Susanville[4]	.04829	.114358	−.045779	8
	Singleleaf pinyon	entire State	−.14240	.148190	−.016712	13
South Dakota	Bur oak	Black Hills	.12853	.105885	0	16
Utah	Mountain-mahogany	eastern Utah	−.13363	.128222	.080208	17
	Utah juniper	eastern Utah	−.08728	.135420	−.019587	9
	Utah juniper	western Utah	−.13386	.133726	.036329	6
	Rocky Mountain juniper	eastern Utah	.02434	.119106	0	11
	Pinyon	eastern Utah	−.20296	.150283	.054178	14
	Singleleaf pinyon	western Utah	−.14240	.148190	−.016712	13
Wyoming	Mountain-mahogany	entire State	−.13363	.128222	.080208	17
	Hardwoods[2]	entire State	−.13822	.121850	0	18
	Utah juniper	entire State	−.08728	.135420	−.019587	9
	Rocky Mountain juniper	entire State	.02434	.119106	0	11
	Pinyon	entire State[3]	−.20296	.150283	.054178	14
	Bur oak	Black Hills	.12853	.105885	0	16

[1] The volume equation is: $V = [a + b(DRSQH)^{1/3} + c\ STEM]^3$, where:
V = gross cubic foot volume of wood and bark to a 1.5-inch mbd
DRSQH = DRC (inches) squared times height (feet)
STEM = 1 for single-stem trees; 0 for multiple-stem trees.

[2] This equation is a rough approximation for the following trees: willow, boxelder, maple, hawthorn, ash, locust, and cherry.

[3] Only a few trees were represented in the sample for this State.

[4] These are BLM districts in Nevada.

A recomputed R^2 statistic is listed for each volume equation in table 3. The R^2 statistic was recomputed in the original cubic foot volume scale using the following formula:

$$R^2 = 1 - \frac{(n-1)\sum_{i=1}^{n}(V_i-\hat{V}_i)^2}{(n-p)\sum_{i=1}^{n}(V_i-\overline{V})^2} \qquad (4)$$

where

$\hat{V}_i$ = predicted volume (ft^3) of the ith tree
V_i = visually estimated volume (ft^3) of the ith tree
$\overline{V}$ = mean of n visually estimated volumes (ft^3)
n = number of trees
p = number of model parameters (in this case p=3).

Table 3.—Recomputed R^2 and bias of the cube root transformation for several quantiles of the sample distribution

Volume equation for area or BLM district	Species	R^2	Quantile of sample	Predicted volume	Transformation bias[1]
				Ft³/tree	*Percent*
Great Basin States	Western juniper	0.76	25th	1.8	−5
			50th	5.8	−2
			75th	14.1	−1
			95th	51.6	−1
	Utah juniper	.76	25th	.9	−7
			50th	2.6	−3
			75th	6.3	−2
			95th	17.9	−1
	Singleleaf pinyon	.82	25th	.8	−4
			50th	2.5	−2
			75th	6.5	−1
			95th	20.6	0
Ely BLM	Utah juniper	.72	25th	.4	−9
			50th	1.2	−4
			75th	3.5	−2
			95th	13.9	−1
Winnemucca BLM	Utah juniper	.60	25th	.8	−11
			50th	2.5	−5
			75th	7.2	−3
			95th	25.7	−1
Colorado Plateau States	Oneseed juniper	.88	25th	.9	−8
			50th	2.3	−4
			75th	6.6	−2
			95th	21.5	−1
	Utah juniper	.77	25th	.9	−7
			50th	3.0	−3
			75th	7.4	−2
			95th	19.9	−1
	Rocky Mountain juniper	.70	25th	.8	−7
			50th	2.1	−4
			75th	5.5	−2
			95th	13.6	−1
	Pinyon	.84	25th	.8	−6
			50th	2.6	−3
			75th	6.4	−2
			95th	26.2	−1
Central Rocky Mountain States	Gambel oak	.86			
	Bur oak	.70			
	Mountain-mahogany	.77			
	Hardwoods	.77			

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[1] Bias is the cube root inverse transformation of the volume prediction (from regression) minus the smearing estimator divided by the smearing estimator.

Data from another study were available for checking some of the equations for the Great Basin States (Born and Chojnacky, in preparation). More than 300 P-J trees were destructively sampled for volume. Table 4 shows the percentage error for predicting volume of individual trees grouped in diameter class intervals. The error was large: 20 percent or more in about half of the diameter classes.

In summary, the cube root transformation injected a negligible bias and most of the volume equations had a reasonable R^2. However, considerable volume prediction errors are likely to result from application of these equations in local areas.

Table 4.—Comparison of the Ely Utah juniper, Great Basin Utah juniper, and Great Basin singleleaf pinyon volume equations with actual volume data from Nevada and Utah BLM districts

BLM district	Species	Diameter class	Number of trees	Actual volume[1]	Predicted volume	Error[2]
		Inches		---- *Ft^3/tree* ----		*Percent*
Battle Mountain	Utah juniper	3 – 9.9	5	0.83	1.07	30
		10 – 17.9	16	4.32	3.79	–12
		>18	3	14.22	12.78	–10
	Singleleaf pinyon	3 – 9.9	26	1.81	1.60	–12
		10 – 17.9	19	10.76	7.59	–30
Carson City	Utah juniper	3 – 9.9	6	2.81	1.79	–36
		10 – 17.9	10	5.15	4.68	–9
		>18	1	12.31	8.73	–29
	Singleleaf pinyon	3 – 9.9	43	2.16	1.92	–11
		10 – 17.9	26	15.57	10.79	–29
		>18	3	46.32	36.57	–21
Elko	Utah juniper	3 – 9.9	24	1.11	1.16	4
		10 – 17.9	25	5.00	4.24	–15
		>18	3	13.04	11.96	–8
	Singleleaf pinyon	3 – 9.9	10	1.33	1.22	–8
		10 – 17.9	5	8.22	7.29	–11
Ely	Utah juniper	3 – 9.9	19	0.65	0.95	47
		10 – 17.9	11	5.71	6.25	9
		>18	7	16.30	19.57	20
	Singleleaf pinyon	3 – 9.9	17	1.21	1.05	–13
		10 – 17.9	8	8.85	7.35	–17
Las Vegas	Utah juniper	10 – 17.9	1	7.77	6.36	–18
	Singleleaf pinyon	10 – 17.9	6	17.69	11.74	–34
		>18	1	55.03	29.02	–47
Richfield	Utah juniper	3 – 9.9	2	2.05	1.75	–15
		10 – 17.9	4	8.51	5.84	–31
		>18	2	20.53	15.17	–26
Total	Utah juniper	3 – >18	139	4.77	4.52	–5
	Singleleaf pinyon	3 – >18	164	7.29	5.42	–26

[1] These are actual volumes computed from tree segments measured by destructively sampling each tree.

[2] Error is predicted volume minus actual volume divided by actual volume.

DISCUSSION

In this study, I searched through a large P-J data set and developed easy-to-use volume equations (and tables) with standardized measurements for predictor variables for the central Rocky Mountain States. However, there might be some concern about the reliability of these equations from the results of table 4. This concern is legitimate if the volume equations from this study are used for local areas. The discrepancy between the volume equation and the volume data given in table 4 clearly illustrates this concern. On the other hand, these volume equations are probably adequate for large Statewide woodland inventories. This is because the trees sampled in an inventory covering an entire State would likely represent most of the diverse tree forms used to obtain the regression coefficient listed in table 2. However, local inventories would be less likely to sample tree forms matching the tree form occurrence in this study. So results such as those in table 4 might be expected if these equations are used for local areas.

I see two possible approaches for future work on P-J volume equations. A more precise volume equation could be sought, or a simple model form such as the one presented in this study could be localized for each application.

Building a better P-J volume equation may require considerable effort. A stem measure that reflects both numbers and volume of each main stem of a multiple-stem tree may be one avenue for improvement. However, developing high precision broadly applicable P-J volume equations requires more knowledge of site and tree biology variables.

Development of local volume equations for each application is perhaps the best means, at present, to obtain precise P-J volume estimates. This is a fairly simple task as a subsample of trees from an inventory can easily be measured for volume by using visual segmentation (Born and Chojnacky, in preparation). A regression equation, volume equation can then be developed that reflects the diverse tree forms specific to the area of interest.

There is still much to learn about volume prediction in P-J woodlands. This study indicates need for more creative, scientific thinking in the future and less massive data collection.

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APPENDIX A

This appendix contains a glossary, a list of species mentioned in the text, maps showing the geographic location of the data (figs. 8 to 11), and summary statistics of the raw data by area and species (table 5).

Glossary of Terms

CRMX	The maximum horizontal diameter of a tree's crown.
CRMN	A tree's crown diameter that is roughly perpendicular to CRMX. (For an elliptical crown this is a minimum crown diameter.)
DRC	Diameter of a tree at the root collar.
DRSQH	DRC squared times height.
EDRC	An equivalent diameter of a tree that forks at the root collar: $EDRC = \sqrt{\sum_{i=1}^{n} DRC_i^2}$
Gross volume	Volume of a tree's wood and bark (includes dead material) from DRC to a 1.5-inch minimum branch diameter.
HT	Total height of a tree from DRC to the tip of the tallest stem perpendicular to DRC.
mbd	Minimum branch diameter.
STEM	A dummy variable with values: 1 for single-stem trees and 0 for multiple-stem trees.
Tree	A woody plant species capable of yielding an aggregate 8 linear feet of wood and bark, from stem(s) and branch material at least 1.5 inches in diameter.
Woodland	Forest land where tree cover is at least 90 percent non-timber (normally not used by the forest products industry) tree species.

Species List

Common name	**Scientific name**
Oneseed juniper	*Juniperus monosperma*
Rocky Mountain juniper	*Juniperus scopulorum*
Utah juniper	*Juniperus osteosperma*
Western juniper	*Juniperus occidentalis*
Pinyon	*Pinus edulis*
Singleleaf pinyon	*Pinus monophylla*
Mountain-mahogany	*Cercocarpus* sp.
Bur oak	*Quercus macrocarpa*
Gambel oak	*Quercus gambelii*
Hardwoods	
ash	*Fraxinus* sp.
boxelder	*Acer negundo*
cherry	*Prunus* sp.
hawthorn	*Crataegus* sp.
locust	*Robinia neomexicana*
maple	*Acer glabrum*
willow	*Salix* sp.

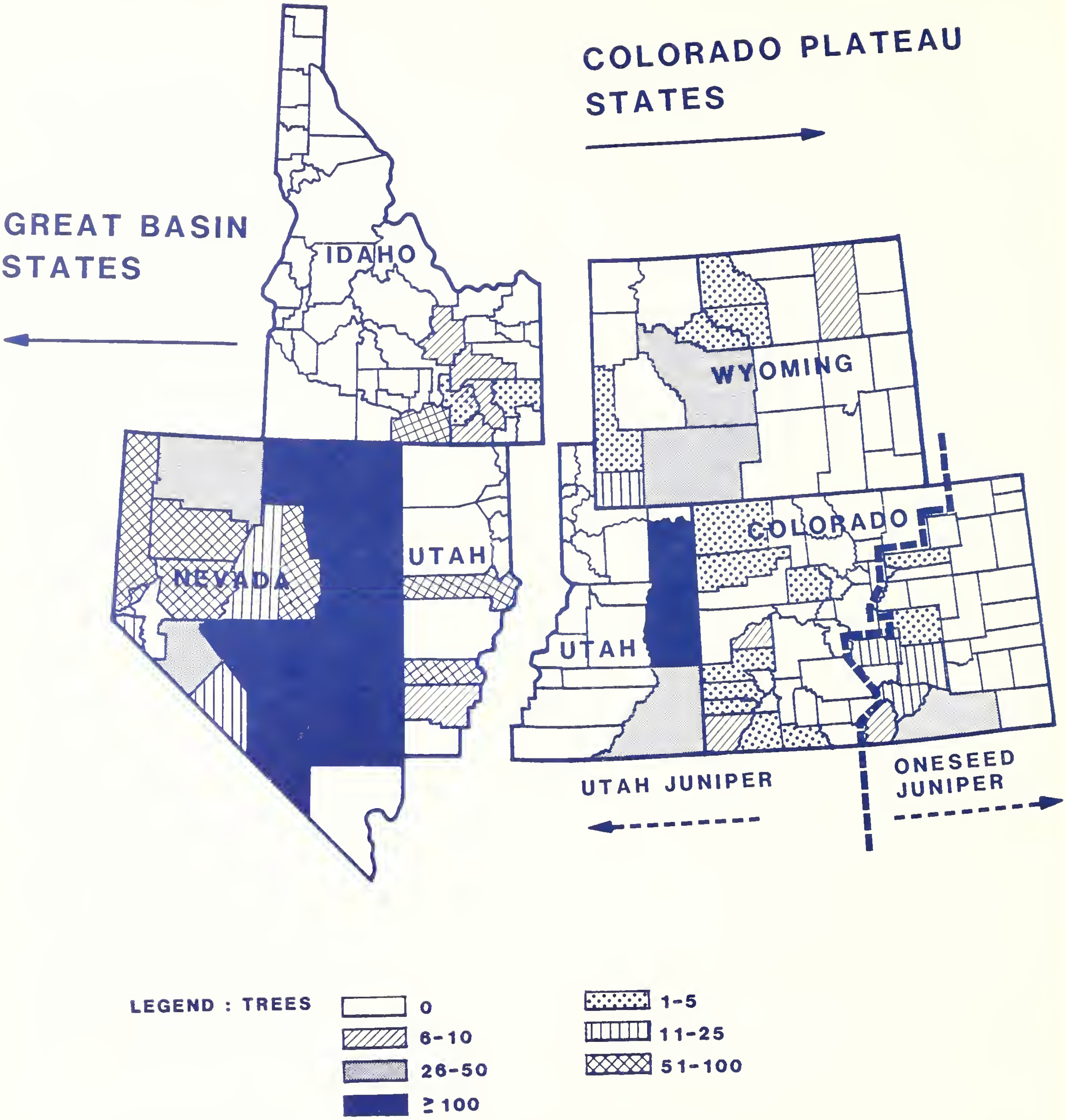

Figure 8.—Data distribution map of Utah juniper and oneseed juniper trees sampled.

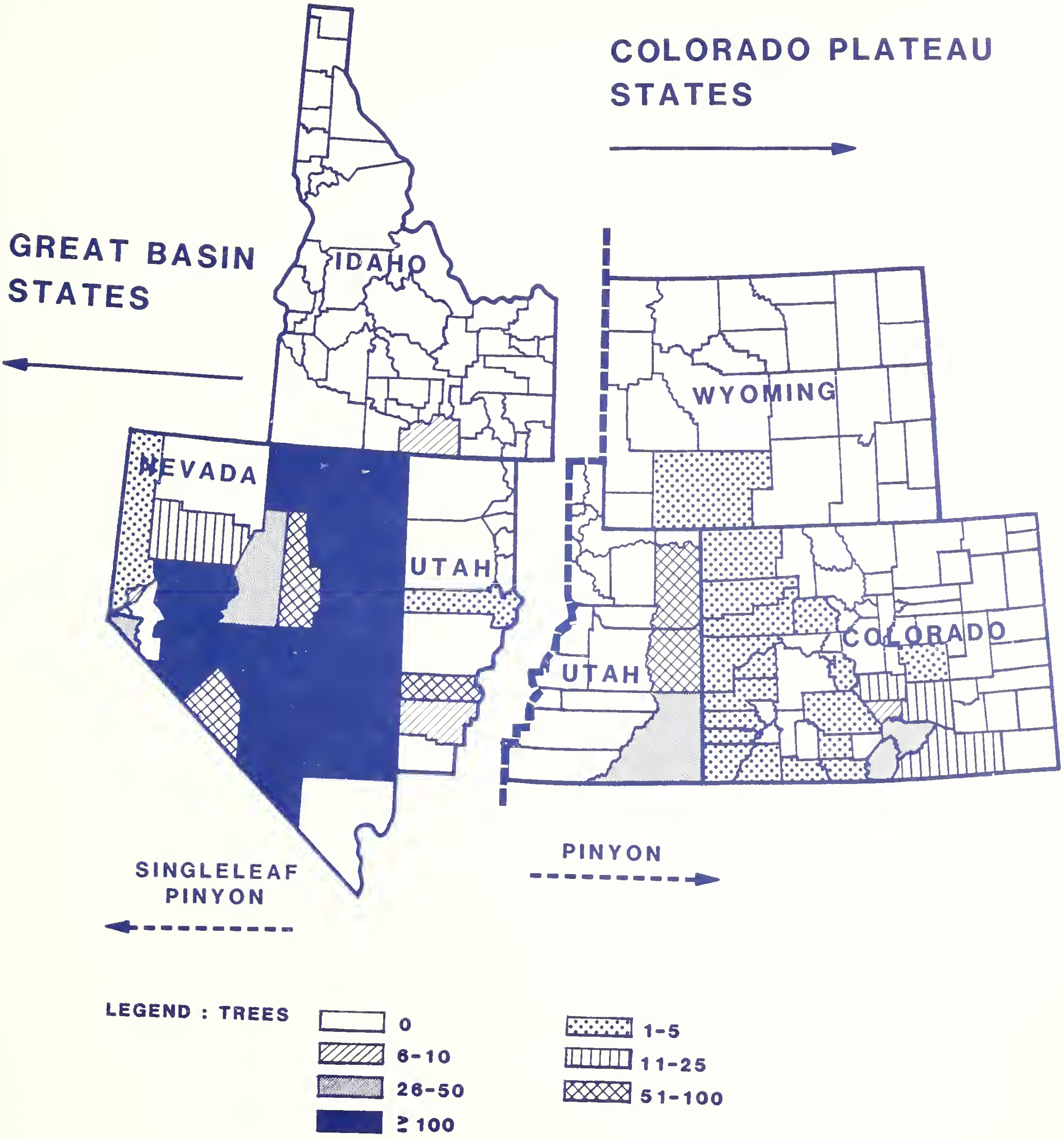

Figure 9.—Data distribution map of singleleaf pinyon and pinyon trees sampled.

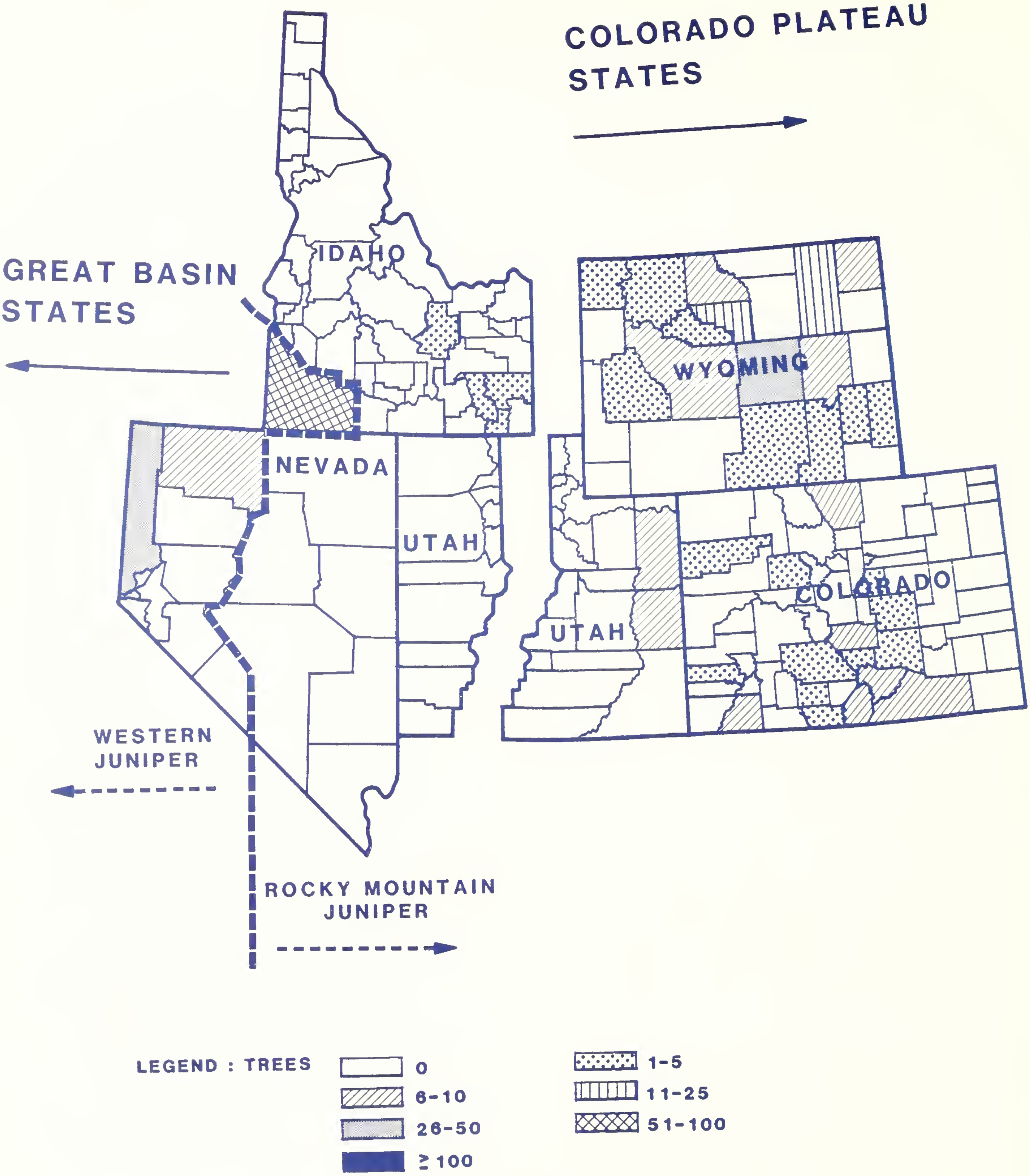

Figure 10.—Data distribution map of western juniper and Rocky Mountain juniper trees sampled.

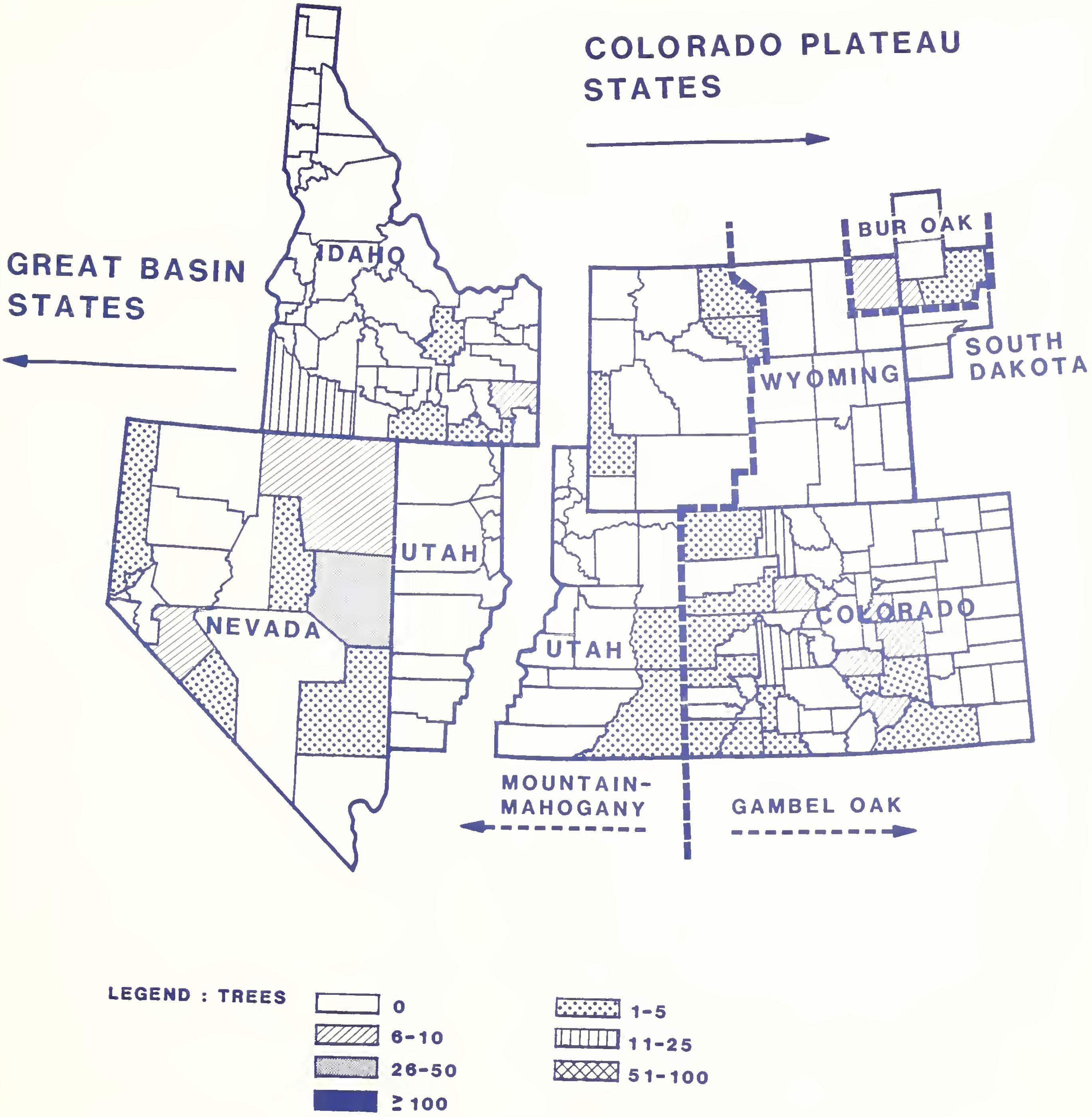

Figure 11.—Data distribution map of mountain-mahogany, Gambel oak, and bur oak sampled.

Table 5.—Summary statistics of volume (ft^3), DRC (inches), and height (ft) data by area and species

Area or BLM district	Species	Number of trees	Percentage[1] single stem	Variable	Mean	Quantiles		
						50th	75th	95th
Colorado	Oneseed juniper	100	40	Volume	6.0	2.2	7.5	24.2
				DRC	13.0	11.0	17.0	26.0
				Height	12.0	11.0	14.0	19.0
	Utah juniper	29	59	Volume	7.7	3.1	9.5	36.6
				DRC	13.0	12.0	17.0	29.0
				Height	14.0	14.0	18.0	27.0
	Rocky Mountain juniper	61	74	Volume	4.4	1.4	7.1	15.3
				DRC	10.0	9.0	13.0	19.0
				Height	14.0	13.0	17.0	23.0
	Pinyon	183	84	Volume	4.6	2.9	5.8	16.3
				DRC	9.0	9.0	12.0	19.0
				Height	14.0	13.0	17.0	25.0
	Gambel oak	94	93	Volume	0.8	0.3	0.6	3.6
				DRC	4.0	4.0	5.0	9.0
				Height	12.0	10.0	14.0	22.0
Idaho	Utah juniper	90	47	Volume	4.8	2.4	5.2	17.6
				DRC	11.0	10.0	14.0	21.0
				Height	12.0	12.0	15.0	18.0
	Rocky Mountain juniper	16	63	Volume	4.1	2.5	6.4	12.7
				DRC	13.0	12.0	16.0	27.0
				Height	15.0	14.0	20.0	25.0
	Western juniper	134	83	Volume	11.8	6.0	15.3	48.4
				DRC	14.0	13.0	18.0	30.0
				Height	22.0	22.0	27.0	37.0
Battle Mountain	Utah juniper	[2]117	58	Volume	3.9	1.4	3.7	15.3
				DRC	10.0	9.0	13.0	24.0
				Height	11.0	10.0	13.0	18.0
	Singleleaf pinyon	[2]228	87	Volume	5.1	2.0	6.3	20.3
				DRC	9.0	8.0	12.0	18.0
				Height	14.0	13.0	17.0	22.0
Carson City	Utah juniper	136	31	Volume	7.1	3.7	8.7	25.6
				DRC	14.0	13.0	19.0	26.0
				Height	12.0	12.0	15.0	20.0
	Singleleaf pinyon	518	76	Volume	7.5	3.5	9.2	27.4
				DRC	11.0	10.0	13.0	21.0
				Height	17.0	16.0	20.0	28.0
Elko	Utah juniper	[2]220	34	Volume	4.5	2.4	6.3	14.4
				DRC	11.0	10.0	15.0	23.0
				Height	12.0	11.0	14.0	19.0
	Singleleaf pinyon	[2]181	79	Volume	5.5	4.1	8.4	15.5
				DRC	10.0	10.0	13.0	16.0
				Height	16.0	15.0	19.0	24.0
Ely	Utah juniper	[2]295	40	Volume	3.6	1.5	3.9	16.8
				DRC	9.0	8.0	12.0	19.0
				Height	10.0	9.0	13.0	19.0
	Singleleaf pinyon	[2]313	78	Volume	3.5	1.1	3.7	15.8
				DRC	8.0	7.0	10.0	16.0
				Height	13.0	12.0	16.0	23.0
Las Vegas	Utah juniper	233	48	Volume	5.4	3.1	7.1	19.1
				DRC	12.0	11.0	16.0	23.0
				Height	13.0	12.0	16.0	21.0
	Singleleaf pinyon	149	86	Volume	4.7	1.5	5.9	18.8
				DRC	9.0	7.0	12.0	19.0
				Height	14.0	13.0	18.0	25.0
Winnemucca and Susanville	Utah juniper	168	37	Volume	8.1	2.9	8.5	36.2
				DRC	15.0	13.0	19.0	33.0
				Height	11.0	11.0	14.0	19.0
	Singleleaf pinyon	20	85	Volume	4.8	2.3	5.4	41.3
				DRC	9.0	8.0	11.0	22.0
				Height	13.0	15.0	16.0	20.0

(con.)

Table 5.—(con.)

Area or BLM district	Species	Number of trees	Percentage[1] single stem	Variable	Mean	Quantiles		
						50th	75th	95th
Nevada	Western juniper	48	54	Volume	20.1	3.8	15.6	106.4
				DRC	18.0	14.0	21.0	46.0
				Height	16.0	15.0	21.0	29.0
Cedar City	Singleleaf pinyon	[2]57	85	Volume	1.9	0.9	2.2	8.6
				DRC	7.0	6.0	9.0	13.0
				Height	12.0	11.0	15.0	22.0
Moab	Utah juniper	151	48	Volume	6.8	2.7	8.5	31.2
				DRC	13.0	12.0	17.0	26.0
				Height	11.0	11.0	14.0	20.0
	Pinyon	92	79	Volume	7.2	3.0	7.6	39.8
				DRC	10.0	9.0	13.0	20.0
				Height	15.0	15.0	20.0	30.0
Richfield	Utah juniper	96	56	Volume	5.0	3.0	6.3	20.9
				DRC	12.0	11.0	16.0	25.0
				Height	12.0	12.0	15.0	18.0
Vernal and Moab	Rocky Mountain juniper	18	67	Volume	3.6	3.5	5.8	11.1
				DRC	10.0	9.0	13.0	19.0
				Height	14.0	14.0	18.0	26.0
Vernal	Utah juniper	113	40	Volume	5.2	4.2	8.1	15.9
				DRC	13.0	12.0	18.0	23.0
				Height	10.0	10.0	12.0	19.0
	Pinyon	77	90	Volume	6.8	2.7	6.6	33.7
				DRC	10.0	10.0	14.0	21.0
				Height	14.0	12.0	17.0	28.0
Wyoming	Utah juniper	109	34	Volume	4.7	2.4	6.0	18.2
				DRC	13.0	12.0	18.0	27.0
				Height	9.0	8.0	11.0	14.0
	Rocky Mountain juniper	102	39	Volume	4.4	2.1	5.2	17.7
				DRC	12.0	11.0	16.0	25.0
				Height	11.0	9.0	13.0	21.0
Wyoming and South Dakota	Bur oak	14	79	Volume	2.9	1.7	5.4	9.3
				DRC	8.0	8.0	12.0	14.0
				Height	17.0	16.0	18.0	40.0
Central Rocky Mountain States	Hardwoods	29	34	Volume	12.1	2.2	15.7	98.7
				DRC	12.0	10.0	16.0	36.0
				Height	24.0	23.0	31.0	49.0
	Mountain-mahogany	126	37	Volume	2.2	1.0	2.6	7.1
				DRC	9.0	8.0	11.0	17.0
				Height	11.0	11.0	13.0	20.0

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[1] The percentage of single-stem trees is based on all the data (including those trees deleted according to footnote 2).

[2] Data for more trees were available, but (for Nevada BLM readers, this included some 1978 to 1979 data) some multiple-stem trees were deleted due to DRC measurement inconsistencies.

APPENDIX B

This appendix contains gross cubic foot volume tables (tables 6 to 18). These include live and dead wood and bark from DRC to a 1.5-inch minimum branch diameter (mbd) for woodland tree species. The range of the data is outlined.

Table 6.—Gross cubic foot volume for Utah juniper in the Great Basin States

DRC	Basal stems	Height (feet)										
		4	6	8	10	12	14	16	18	20	25	30
Inches		*Cubic feet*										
4	Single	0.08	0.14	0.19	0.25	0.31	0.36	0.42	0.48	0.55		
	Multiple	0.06	0.11	0.16	0.21	0.26	0.31	0.37	0.42	0.48		
6	Single	0.22	0.35	0.48	0.62	0.76	0.90	1.05	1.19	1.33	1.70	2.07
	Multiple	0.18	0.30	0.42	0.55	0.67	0.81	0.94	1.07	1.21	1.55	1.90
8	Single	0.42	0.67	0.92	1.17	1.43	1.69	1.95	2.22	2.48	3.15	3.83
	Multiple	0.37	0.59	0.82	1.06	1.30	1.54	1.79	2.04	2.29	2.93	3.57
10	Single	0.70	1.09	1.50	1.91	2.32	2.73	3.15	3.58	4.00	5.07	6.14
	Multiple	0.62	0.98	1.36	1.74	2.13	2.53	2.93	3.33	3.73	4.75	5.78
12	Single	1.05	1.63	2.22	2.82	3.42	4.03	4.65	5.26	5.88	7.44	9.00
	Multiple	0.94	1.48	2.04	2.61	3.18	3.76	4.35	4.94	5.53	7.03	8.54
14	Single	1.46	2.27	3.09	3.91	4.75	5.59	6.43	7.28	8.13	10.27	12.42
	Multiple	1.33	2.09	2.86	3.65	4.45	5.25	6.06	6.88	7.70	9.77	11.85
16	Single	1.95	3.02	4.10	5.19	6.30	7.40	8.52	9.63	10.75	13.57	16.40
	Multiple	1.79	2.80	3.83	4.87	5.93	7.00	8.07	9.15	10.23	12.96	15.71
18	Single		3.88	5.26	6.66	8.06	9.48	10.89	12.32	13.75	17.34	20.94
	Multiple		3.62	4.94	6.28	7.63	9.00	10.37	11.75	13.13	16.62	20.12
20	Single		4.85	6.57	8.31	10.05	11.81	13.57	15.34	17.11	21.57	26.04
	Multiple		4.55	6.20	7.87	9.55	11.25	12.96	14.68	16.40	20.73	25.09
22	Single		5.93	8.03	10.14	12.27	14.40	16.55	18.70	20.85	26.26	31.70
	Multiple		5.58	7.60	9.64	11.70	13.77	15.85	17.94	20.04	25.31	30.62
24	Single		7.13	9.63	12.16	14.70	17.26	19.82	22.39	24.97	31.43	37.92
	Multiple		6.73	9.15	11.59	14.06	16.54	19.03	21.53	24.05	30.36	36.71
26	Single			11.39	14.37	17.36	20.37	23.39	26.42	29.45	37.07	44.71
	Multiple			10.84	13.73	16.64	19.57	22.51	25.46	28.42	35.87	43.35
28	Single			13.29	16.76	20.25	23.75	27.26	30.78	34.31	43.17	52.06
	Multiple			12.69	16.05	19.45	22.86	26.29	29.73	33.18	41.84	50.55
30	Single			15.34	19.34	23.35	27.39	31.43	35.49	39.55	49.74	59.97
	Multiple			14.68	18.56	22.47	26.41	30.36	34.32	38.30	48.28	58.32
35	Single				26.60	32.11	37.63	43.17	48.72	54.29	68.23	82.23
	Multiple				25.64	31.02	36.42	41.84	47.28	52.74	66.43	80.18

Volume $= [-0.13386 + 0.133726(\mathrm{DRSQH})^{1/3} + 0.036329(\mathrm{STEM})]^3$ where: $\left\{ \begin{array}{l} \text{DRSQH} = \text{DRC squared times height} \\ \text{STEM} = 1 \text{ if single, } 0 \text{ if multiple.} \end{array} \right.$

Table 7.—Gross cubic foot volume for Utah juniper in the Ely BLM District

DRC	Basal stems	Height (feet) 4	6	8	10	12	14	16	18	20	25	30	35	40	50
Inches		*Cubic feet*													
4	Single	0.12	0.18	0.25	0.32	0.39	0.45	0.52	0.59	0.67					
	Multiple	0.13	0.20	0.27	0.34	0.42	0.49	0.56	0.63	0.71					
6	Single	0.28	0.44	0.59	0.75	0.91	1.08	1.24	1.40	1.57	1.98	2.39			
	Multiple	0.31	0.47	0.63	0.80	0.97	1.14	1.30	1.47	1.64	2.07	2.49			
8	Single	0.52	0.81	1.09	1.38	1.67	1.97	2.26	2.56	2.85	3.60	4.34	5.09	5.84	
	Multiple	0.56	0.86	1.15	1.45	1.75	2.06	2.36	2.66	2.97	3.73	4.49	5.26	6.03	
10	Single	0.84	1.29	1.75	2.21	2.67	3.13	3.60	4.06	4.53	5.70	6.88	8.06	9.25	11.62
	Multiple	0.89	1.36	1.83	2.30	2.78	3.25	3.73	4.20	4.68	5.88	7.08	8.29	9.49	11.91
12	Single		1.89	2.56	3.22	3.89	4.57	5.24	5.92	6.60	8.30	10.01	11.72	13.44	16.88
	Multiple		1.98	2.66	3.35	4.03	4.72	5.41	6.10	6.79	8.53	10.27	12.01	13.75	17.24
14	Single			3.52	4.44	5.35	6.28	7.20	8.13	9.06	11.39	13.72	16.06	18.41	23.12
	Multiple			3.65	4.59	5.53	6.47	7.41	8.35	9.30	11.67	14.04	16.42	18.80	23.57
16	Single			4.64	5.84	7.05	8.26	9.47	10.69	11.91	14.96	18.03	21.10	24.18	30.34
	Multiple			4.80	6.03	7.26	8.49	9.72	10.96	12.20	15.30	18.41	21.52	24.64	30.89
18	Single			5.92	7.45	8.98	10.52	12.06	13.61	15.15	19.03	22.92	26.82	30.73	38.56
	Multiple			6.10	7.66	9.22	10.79	12.36	13.93	15.50	19.43	23.37	27.32	31.28	39.19
20	Single			7.35	9.25	11.15	13.05	14.96	16.88	18.79	23.60	28.41	33.24	38.07	47.76
	Multiple			7.56	9.49	11.43	13.36	15.30	17.24	19.19	24.06	28.93	33.82	38.70	48.49
22	Single				11.24	13.55	15.86	18.18	20.50	22.83	28.65	34.50	40.35	46.21	57.95
	Multiple				11.52	13.87	16.22	18.57	20.92	23.28	29.18	35.09	41.00	46.92	58.78
24	Single				13.44	16.19	18.95	21.71	24.48	27.26	34.21	41.17	48.15	55.13	69.13
	Multiple				13.75	16.55	19.34	22.15	24.95	27.76	34.79	41.83	48.88	55.94	70.07
26	Single					19.06	22.31	25.56	28.82	32.08	40.25	48.44	56.64	64.85	81.30
	Multiple					19.46	22.75	26.05	29.34	32.64	40.90	49.18	57.46	65.75	82.35
28	Single					22.17	25.95	29.73	33.51	37.30	46.79	56.30	65.82	75.36	94.47
	Multiple					22.62	26.44	30.26	34.09	37.92	47.51	57.12	66.73	76.35	95.62
30	Single						29.86	34.21	38.56	42.91	53.82	64.75	75.70	86.66	108.62
	Multiple						30.40	34.79	39.19	43.60	54.62	65.65	76.70	87.75	109.89
35	Single						40.86	46.79	52.73	58.68	73.57	88.49	103.43	118.39	148.34
	Multiple						41.52	47.51	53.51	59.52	74.55	89.60	104.66	119.73	149.90
40	Single							61.35	69.13	76.92	96.42	115.95	135.50	155.07	194.27
	Multiple							62.22	70.07	77.93	97.59	117.27	136.97	156.68	196.13
50	Single							96.42	108.62	120.83	151.40	182.01	212.66	243.33	304.74
	Multiple							97.59	109.89	122.19	152.98	183.80	214.64	245.50	307.26

$\text{Volume} = [-0.03655 + 0.135689(\text{DRSQH})^{1/3} - 0.018476(\text{STEM})]^3$ where: $\begin{cases} \text{DRSQH} = \text{DRC squared times height} \\ \text{STEM} = 1 \text{ if single, } 0 \text{ if multiple.} \end{cases}$

Table 8.—Gross cubic foot volume for Utah juniper in the Winnemucca and Susanville BLM Districts

DRC	Basal stems	Height (feet) 4	6	8	10	12	14	16	18	20	25	30
Inches		*Cubic feet*										
4	Single	0.10	0.15	0.19	0.24	0.29	0.34	0.39	0.44	0.48		
	Multiple	0.13	0.19	0.24	0.30	0.35	0.41	0.46	0.52	0.57		
6	Single	0.22	0.33	0.44	0.54	0.65	0.76	0.87	0.98	1.08	1.36	
	Multiple	0.27	0.40	0.52	0.64	0.76	0.88	1.00	1.12	1.24	1.53	
8	Single	0.39	0.58	0.77	0.96	1.16	1.35	1.54	1.73	1.93	2.41	
	Multiple	0.46	0.68	0.89	1.10	1.31	1.52	1.73	1.94	2.15	2.66	
10	Single	0.60	0.90	1.20	1.51	1.81	2.11	2.41	2.71	3.01	3.76	
	Multiple	0.71	1.04	1.37	1.69	2.02	2.34	2.66	2.98	3.30	4.10	
12	Single	0.87	1.30	1.73	2.17	2.60	3.03	3.46	3.90	4.33	5.41	6.49
	Multiple	1.00	1.47	1.94	2.40	2.87	3.33	3.79	4.25	4.70	5.84	6.98
14	Single	1.18	1.77	2.36	2.95	3.53	4.12	4.71	5.30	5.89	7.36	8.83
	Multiple	1.34	1.98	2.61	3.24	3.86	4.49	5.11	5.73	6.35	7.89	9.43
16	Single		2.31	3.08	3.85	4.62	5.38	6.15	6.92	7.69	9.61	11.52
	Multiple		2.56	3.38	4.19	5.01	5.82	6.62	7.43	8.23	10.24	12.24
18	Single		2.92	3.90	4.87	5.84	6.81	7.78	8.75	9.73	12.15	14.58
	Multiple		3.21	4.25	5.27	6.30	7.32	8.33	9.35	10.36	12.89	15.42
20	Single		3.61	4.81	6.01	7.21	8.41	9.61	10.80	12.00	15.00	18.00
	Multiple		3.94	5.21	6.47	7.73	8.99	10.24	11.49	12.74	15.85	18.96
22	Single		4.36	5.82	7.27	8.72	10.17	11.62	13.07	14.52	18.15	21.77
	Multiple		4.74	6.27	7.79	9.31	10.83	12.34	13.85	15.35	19.11	22.86
24	Single			6.92	8.65	10.37	12.10	13.83	15.55	17.28	21.59	25.91
	Multiple			7.43	9.24	11.04	12.84	14.63	16.42	18.21	22.68	27.13
26	Single			8.12	10.15	12.17	14.20	16.22	18.25	20.28	25.34	30.40
	Multiple			8.69	10.80	12.91	15.02	17.12	19.22	21.31	26.54	31.76
28	Single			9.41	11.76	14.11	16.46	18.81	21.16	23.51	29.38	35.26
	Multiple			10.04	12.49	14.93	17.37	19.80	22.23	24.66	30.71	36.75
30	Single			10.80	13.50	16.20	18.90	21.59	24.29	26.99	33.73	40.47
	Multiple			11.49	14.30	17.10	19.89	22.68	25.46	28.24	35.18	42.11
35	Single				18.37	22.04	25.71	29.38	33.05	36.72	45.90	55.07
	Multiple				19.35	23.14	26.93	30.71	34.49	38.26	47.68	57.08
40	Single					28.79	33.58	38.37	43.16	47.96	59.94	71.92
	Multiple					30.09	35.03	39.96	44.88	49.79	62.07	74.32
50	Single							59.94	67.42	74.91	93.63	112.34
	Multiple							62.07	69.72	77.38	96.49	115.57

Volume = $[0.04829 + 0.114358(\mathrm{DRSQH})^{1/3} - 0.045779(\mathrm{STEM})]^3$ where: $\left\{\begin{array}{l}\mathrm{DRSQH} = \text{DRC squared times height} \\ \mathrm{STEM} = 1 \text{ if single, } 0 \text{ if multiple.}\end{array}\right.$

Table 9.—Gross cubic foot volume for Utah juniper in Colorado Plateau States

DRC	Basal stems	Height (feet)										
		4	6	8	10	12	14	16	18	20	25	30
Inches		*Cubic feet*										
4	Single	0.08	0.14	0.19	0.25	0.31	0.37	0.43	0.49	0.55		
	Multiple	0.09	0.15	0.21	0.27	0.33	0.40	0.46	0.53	0.59		
6	Single	0.22	0.35	0.49	0.63	0.77	0.91	1.06	1.21	1.36	1.73	2.11
	Multiple	0.24	0.38	0.53	0.67	0.82	0.97	1.12	1.28	1.43	1.82	2.21
8	Single	0.43	0.68	0 93	1.19	1.46	1.72	1.99	2.26	2.53	3.22	3.92
	Multiple	0.46	0.72	0.99	1.26	1.53	1.81	2.09	2.36	2.65	3.35	4.06
10	Single	0.71	1.11	1.52	1.94	2.36	2.79	3.22	3.66	4.09	5.19	6.29
	Multiple	0.75	1.17	1.60	2.03	2.47	2.91	3.35	3.80	4.24	5.37	6.50
12	Single	1.06	1.66	2.26	2.88	3.50	4.13	4.76	5.39	6.03	7.63	9.24
	Multiple	1.12	1.74	2.36	3.00	3.64	4.28	4.92	5.57	6.22	7.86	9.50
14	Single	1.49	2.31	3.15	4.00	4.86	5.73	6.60	7.47	8.35	10.55	12.77
	Multiple	1.57	2.42	3.28	4.15	5.03	5.92	6.80	7.70	8.59	10.84	13.09
16	Single	1.99	3.08	4.20	5.32	6.45	7.59	8.74	9.89	11.05	13.95	16.87
	Multiple	2.09	3.21	4.35	5.50	6.66	7.82	8.99	10.16	11.34	14.30	17.26
18	Single	2.57	3.97	5.39	6.83	8.27	9.73	11.19	12.66	14.13	17.84	21.56
	Multiple	2.68	4.12	5.57	7.04	8.52	10.00	11.49	12.98	14.48	18.24	22.02
20	Single	3.22	4.97	6.74	8.52	10.32	12.13	13.95	15.78	17.61	22.20	26.82
	Multiple	3.35	5.14	6.95	8.77	10.61	12.45	14.30	16.15	18.01	22.67	27.35
22	Single		6.08	8.24	10.41	12.61	14.81	17.02	19.24	21.47	27.06	32.67
	Multiple		6.28	8.48	10.70	12.93	15.17	17.41	19.67	21.92	27.59	33.28
24	Single			9.89	12.50	15.12	17.75	20.40	23.05	25.71	32.39	39.10
	Multiple			10.16	12.82	15.48	18.16	20.84	23.53	26.23	32.99	39.78
26	Single			11.70	14.77	17.86	20.97	24.09	27.21	30.35	38.22	46.12
	Multiple			12.00	15.13	18.27	21.42	24.58	27.75	30.92	38.89	46.88
28	Single			13.66	17.24	20.84	24.46	28.08	31.72	35.37	44.52	53.72
	Multiple			14.00	17.64	21.29	24.95	28.63	32.32	36.01	45.27	54.56
30	Single			15.78	19.90	24.05	28.21	32.39	36.58	40.78	51.32	61.90
	Multiple			16.15	20.34	24.54	28.76	32.99	37.23	41.48	52.14	62.82
35	Single				27.40	33.09	38.80	44.52	50.27	56.02	70.44	84.92
	Multiple				27.94	33.70	39.48	45.27	51.07	56.88	71.45	86.06
40	Single					43.59	51.09	58.60	66.14	73.69	92.62	111.61
	Multiple					44.32	51.90	59.50	67.10	74.73	93.83	112.97

Volume $= [-0.08728 + 0.135420(\mathrm{DRSQH})^{1/3} - 0.019587(\mathrm{STEM})]^3$ where: $\left\{\begin{array}{l}\text{DRSQH} = \text{DRC squared times height} \\ \text{STEM} = 1 \text{ if single, 0 if multiple.}\end{array}\right.$

Table 10.—Gross cubic foot volume for western juniper in the Great Basin States

DRC	Basal stems	Height (feet)													
		4	6	8	10	12	14	16	18	20	25	30	35	40	50
Inches		*Cubic feet*													
4	Single	0.06	0.09	0.13	0.18	0.22	0.26	0.31	0.36	0.40					
	Multiple	0.02	0.04	0.07	0.10	0.13	0.16	0.19	0.22	0.26					
6	Single	0.16	0.25	0.36	0.46	0.57	0.68	0.79	0.90	1.01	1.30	1.59			
	Multiple	0.08	0.15	0.22	0.30	0.39	0.47	0.56	0.65	0.74	0.97	1.21			
8	Single	0.31	0.50	0.69	0.89	1.09	1.29	1.50	1.71	1.92	2.44	2.98	3.52	4.07	
	Multiple	0.19	0.33	0.48	0.64	0.80	0.97	1.14	1.31	1.49	1.94	2.40	2.87	3.35	
10	Single	0.52	0.82	1.14	1.46	1.78	2.11	2.44	2.78	3.11	3.96	4.82	5.68	6.55	8.30
	Multiple	0.35	0.59	0.84	1.11	1.38	1.66	1.94	2.23	2.52	3.26	4.01	4.78	5.56	7.13
12	Single		1.24	1.71	2.18	2.66	3.14	3.63	4.12	4.61	5.86	7.11	8.38	9.65	12.20
	Multiple		0.93	1.31	1.71	2.12	2.54	2.97	3.40	3.83	4.93	6.06	7.20	8.35	10.68
14	Single		1.75	2.39	3.05	3.71	4.38	5.05	5.73	6.41	8.13	9.86	11.60	13.35	16.87
	Multiple		1.35	1.89	2.46	3.04	3.62	4.22	4.82	5.43	6.97	8.54	10.13	11.73	14.97
16	Single		2.34	3.20	4.07	4.94	5.83	6.72	7.62	8.52	10.78	13.06	15.36	17.66	22.30
	Multiple		1.85	2.59	3.35	4.12	4.91	5.71	6.51	7.32	9.38	11.47	13.57	15.70	20.00
18	Single		3.02	4.12	5.23	6.36	7.49	8.63	9.77	10.92	13.81	16.72	19.65	22.59	28.49
	Multiple		2.44	3.40	4.38	5.38	6.40	7.43	8.46	9.51	12.16	14.84	17.54	20.27	25.78
20	Single			5.16	6.55	7.95	9.36	10.78	12.20	13.63	17.23	20.84	24.48	28.13	35.46
	Multiple			4.32	5.56	6.82	8.09	9.38	10.68	11.99	15.30	18.65	22.03	25.44	32.32
22	Single			6.33	8.02	9.73	11.45	13.18	14.91	16.65	21.03	25.43	29.85	34.28	43.20
	Multiple			5.36	6.88	8.43	9.99	11.57	13.16	14.77	18.82	22.92	27.05	31.21	39.61
24	Single			7.62	9.65	11.69	13.75	15.82	17.89	19.98	25.21	30.47	35.75	41.06	51.71
	Multiple			6.51	8.35	10.21	12.10	14.00	15.92	17.85	22.71	27.63	32.59	37.59	47.65
26	Single				11.42	13.83	16.26	18.70	21.15	23.61	29.77	35.98	42.20	48.45	60.99
	Multiple				9.96	12.18	14.41	16.66	18.94	21.22	26.98	32.80	38.67	44.57	56.46
28	Single					16.16	18.99	21.83	24.68	27.54	34.73	41.94	49.19	56.46	71.05
	Multiple					14.32	16.93	19.57	22.22	24.89	31.63	38.42	45.27	52.15	66.02
30	Single						21.93	25.21	28.49	31.79	40.06	48.37	56.72	65.09	81.88
	Multiple						19.66	22.71	25.78	28.87	36.65	44.50	52.40	60.35	76.35
35	Single						30.23	34.73	39.23	43.75	55.09	66.48	77.91	89.37	112.36
	Multiple						27.41	31.63	35.87	40.13	50.86	61.67	72.56	83.50	105.51
40	Single						39.88	45.78	51.71	57.65	72.54	87.49	102.49	117.53	147.69
	Multiple						36.47	42.05	47.65	53.28	67.44	81.71	96.06	110.47	139.46
50	Single							72.54	81.88	91.24	114.71	138.25	161.86	185.52	232.95
	Multiple							67.44	76.35	85.29	107.76	130.38	153.11	175.92	221.77

Volume $= [-0.22048 + 0.125468(\text{DRSQH})^{1/3} + 0.100092(\text{STEM})]^3$ where: $\left\{\begin{array}{l}\text{DRSQH} = \text{DRC squared times height} \\ \text{STEM} = 1 \text{ if single, } 0 \text{ if multiple.}\end{array}\right.$

Table 11.—Gross cubic foot volume for either single-stem or multiple-stem Rocky Mountain juniper in the Colorado Plateau States and Idaho

	Height (feet)											
DRC	4	6	8	10	12	14	16	18	20	25	30	35
Inches	*Cubic feet*											
4	0.13	0.18	0.24	0.30	0.36	0.42	0.48	0.53	0.59			
6	0.27	0.40	0.53	0.66	0.79	0.92	1.05	1.17	1.30	1.62	1.94	
8	0.48	0.71	0.93	1.16	1.39	1.61	1.84	2.06	2.29	2.85	3.41	3.96
10	0.73	1.09	1.44	1.80	2.15	2.50	2.85	3.20	3.55	4.42	5.29	6.16
12	1.05	1.56	2.06	2.57	3.07	3.57	4.08	4.58	5.08	6.33	7.58	8.82
14	1.41	2.10	2.79	3.48	4.16	4.84	5.52	6.20	6.88	8.58	10.28	11.97
16	1.84	2.74	3.63	4.52	5.41	6.30	7.19	8.08	8.96	11.17	13.38	15.59
18	2.32	3.45	4.58	5.70	6.83	7.95	9.07	10.19	11.31	14.11	16.90	19.69
20		4.25	5.63	7.02	8.41	9.79	11.17	12.56	13.94	17.38	20.82	24.26
22		5.12	6.80	8.48	10.15	11.82	13.49	15.16	16.83	21.00	25.16	29.31
24		6.08	8.08	10.07	12.06	14.05	16.03	18.02	20.00	24.95	29.90	34.84
26		7.12	9.46	11.80	14.13	16.46	18.79	21.11	23.44	29.24	35.04	40.84
28		8.24	10.95	13.66	16.36	19.06	21.76	24.45	27.15	33.88	40.60	47.31
30			12.56	15.66	18.76	21.86	24.95	28.04	31.13	38.85	46.56	54.26
35				21.25	25.46	29.67	33.88	38.08	42.28	52.77	63.25	73.72
40					33.19	38.68	44.16	49.64	55.12	68.81	82.48	96.15

Volume $= [0.02434 + 0.119106(\mathrm{DRSQH})^{1/3}]^3$ where: DRSQH = DRC squared times height.

Table 12.—Gross cubic foot volume for oneseed juniper in eastern Colorado

		Height (feet)										
DRC	Basal stems	4	6	8	10	12	14	16	18	20	25	30
Inches		*Cubic feet*										
4	Single	0.06	0.10	0.15	0.20	0.25	0.30	0.36	0.41			
	Multiple	0.04	0.08	0.12	0.16	0.21	0.25	0.30	0.35			
6	Single	0.17	0.29	0.41	0.54	0.67	0.80	0.93	1.07	1.21		
	Multiple	0.14	0.24	0.35	0.47	0.58	0.70	0.83	0.95	1.08		
8	Single	0.36	0.58	0.81	1.05	1.30	1.55	1.80	2.06	2.31		
	Multiple	0.30	0.50	0.72	0.94	1.17	1.40	1.64	1.88	2.12		
10	Single	0.61	0.98	1.36	1.75	2.15	2.56	2.97	3.38	3.79		
	Multiple	0.53	0.87	1.23	1.59	1.97	2.35	2.74	3.13	3.52		
12	Single	0.93	1.49	2.06	2.64	3.23	3.83	4.43	5.04	5.65	7.20	
	Multiple	0.83	1.34	1.88	2.43	2.99	3.55	4.13	4.71	5.30	6.78	
14	Single	1.33	2.10	2.90	3.71	4.53	5.36	6.20	7.04	7.89	10.03	
	Multiple	1.20	1.92	2.67	3.44	4.23	5.02	5.82	6.63	7.45	9.51	
16	Single		2.83	3.89	4.97	6.06	7.16	8.27	9.39	10.51	13.34	16.20
	Multiple		2.61	3.62	4.65	5.69	6.75	7.81	8.89	9.97	12.71	15.48
18	Single		3.68	5.04	6.42	7.82	9.23	10.65	12.08	13.52	17.14	20.79
	Multiple		3.41	4.71	6.04	7.38	8.74	10.11	11.49	12.88	16.39	19.93
20	Single		4.63	6.34	8.07	9.81	11.57	13.34	15.13	16.91	21.42	25.96
	Multiple		4.32	5.95	7.61	9.30	11.00	12.71	14.44	16.17	20.55	24.97
22	Single			7.79	9.90	12.03	14.18	16.34	18.51	20.70	26.19	31.71
	Multiple			7.35	9.38	11.44	13.52	15.61	17.72	19.84	25.19	30.58
24	Single			9.39	11.93	14.48	17.06	19.65	22.25	24.87	31.44	38.06
	Multiple			8.89	11.34	13.81	16.31	18.83	21.36	23.90	30.31	36.77
26	Single			11.15	14.14	17.17	20.21	23.27	26.34	29.43	37.18	44.98
	Multiple			10.59	13.48	16.41	19.37	22.35	25.34	28.35	35.92	43.55
28	Single			13.06	16.56	20.08	23.63	27.20	30.78	34.37	43.41	52.50
	Multiple			12.43	15.82	19.25	22.70	26.17	29.67	33.18	42.01	50.91
30	Single				19.16	23.23	27.32	31.44	35.57	39.72	50.13	60.61
	Multiple				18.35	22.31	26.30	30.31	34.35	38.40	48.59	58.85
35	Single				26.53	32.13	37.76	43.41	49.09	54.78	69.08	83.45
	Multiple				25.52	30.98	36.48	42.01	47.57	53.14	67.17	81.28

Volume $= [-0.19321 + 0.136101(\mathrm{DRSQH})^{1/3} + 0.038187(\mathrm{STEM})]^3$ where: $\begin{cases} \text{DRSQH = DRC squared times height} \\ \text{STEM = 1 if single, 0 if multiple.} \end{cases}$

Table 13.—Gross cubic foot volume for singleleaf pinyon in the Great Basin States

DRC	Basal stems	Height (feet)													
		4	6	8	10	12	14	16	18	20	25	30	35	40	50
Inches		Cubic feet													
4	Single	0.08	0.14	0.20	0.27	0.34	0.41	0.48	0.55	0.62					
	Multiple	0.09	0.15	0.22	0.29	0.36	0.43	0.51	0.58	0.66					
6	Single	0.24	0.39	0.55	0.72	0.89	1.06	1.24	1.42	1.60	2.06	2.52			
	Multiple	0.26	0.42	0.58	0.76	0.93	1.11	1.30	1.48	1.67	2.14	2.62			
8	Single	0.48	0.77	1.08	1.40	1.72	2.05	2.38	2.71	3.05	3.90	4.76	5.64	6.52	
	Multiple	0.51	0.82	1.13	1.46	1.79	2.13	2.47	2.81	3.15	4.03	4.91	5.80	6.70	
10	Single	0.81	1.30	1.80	2.31	2.84	3.37	3.90	4.44	4.98	6.35	7.74	9.14	10.55	13.39
	Multiple	0.86	1.36	1.88	2.40	2.94	3.48	4.03	4.58	5.13	6.53	7.94	9.36	10.79	13.68
12	Single	1.24	1.96	2.71	3.47	4.24	5.03	5.81	6.61	7.41	9.42	11.46	13.51	15.57	19.74
	Multiple	1.30	2.04	2.81	3.59	4.38	5.17	5.98	6.79	7.60	9.65	11.71	13.80	15.89	20.10
14	Single	1.76	2.77	3.81	4.87	5.95	7.03	8.12	9.22	10.32	13.11	15.92	18.75	21.60	27.33
	Multiple	1.83	2.87	3.94	5.02	6.11	7.21	8.32	9.44	10.56	13.39	16.24	19.11	21.99	27.79
16	Single		3.73	5.11	6.52	7.94	9.38	10.82	12.28	13.74	17.42	21.13	24.87	28.62	36.18
	Multiple		3.85	5.26	6.70	8.14	9.60	11.07	12.54	14.03	17.76	21.52	25.30	29.09	36.73
18	Single		4.83	6.61	8.41	10.23	12.07	13.92	15.78	17.65	22.35	27.09	31.86	36.65	46.29
	Multiple		4.97	6.79	8.62	10.47	12.34	14.21	16.10	17.99	22.75	27.55	32.37	37.21	46.94
20	Single			8.30	10.55	12.82	15.11	17.42	19.74	22.06	27.92	33.81	39.74	45.69	57.66
	Multiple			8.51	10.79	13.10	15.42	17.76	20.10	22.46	28.38	34.34	40.32	46.34	58.41
22	Single				12.94	15.71	18.51	21.32	24.14	26.98	34.11	41.28	48.50	55.74	70.30
	Multiple				13.22	16.03	18.86	21.70	24.56	27.43	34.64	41.89	49.17	56.48	71.16
24	Single				15.57	18.90	22.25	25.62	29.00	32.39	40.93	49.51	58.14	66.81	84.21
	Multiple				15.89	19.26	22.65	26.05	29.47	32.90	41.52	50.19	58.90	67.64	85.18
26	Single					22.39	26.34	30.32	34.31	38.31	48.38	58.50	68.68	78.89	99.40
	Multiple					22.79	26.79	30.81	34.84	38.89	49.05	59.26	69.52	79.81	100.48
28	Single					26.18	30.79	35.42	40.07	44.74	56.46	68.25	80.10	91.98	115.85
	Multiple					26.62	31.28	35.96	40.66	45.37	57.20	69.09	81.03	93.01	117.04
30	Single						35.59	40.93	46.29	51.67	65.18	78.76	92.41	106.09	133.58
	Multiple						36.13	41.52	46.94	52.37	66.00	79.69	93.43	107.22	134.89

$$\text{Volume} = [-0.14240 + 0.148190(\text{DRSQH})^{1/3} - 0.016712(\text{STEM})]^3 \text{ where: } \begin{cases} \text{DRSQH} = \text{DRC squared times height} \\ \text{STEM} = 1 \text{ if single, 0 if multiple.} \end{cases}$$

Table 14.—Gross cubic foot volume for pinyon in the Colorado Plateau States

DRC	Basal stems	4	6	8	10	12	14	16	18	20	25	30	35	40	50
		Height (feet)													
Inches		Cubic feet													
4	Single	0.09	0.16	0.23	0.30	0.37	0.45	0.52	0.60	0.68					
	Multiple	0.06	0.11	0.17	0.23	0.29	0.36	0.42	0.49	0.56					
6	Single	0.26	0.43	0.60	0.78	0.96	1.15	1.34	1.53	1.72	2.21	2.70			
	Multiple	0.20	0.34	0.49	0.65	0.81	0.98	1.15	1.32	1.50	1.94	2.40			
8	Single	0.52	0.84	1.17	1.51	1.85	2.20	2.55	2.90	3.26	4.17	5.08	6.00	6.94	
	Multiple	0.42	0.70	1.00	1.30	1.62	1.93	2.26	2.59	2.92	3.76	4.61	5.48	6.36	
10	Single	0.88	1.40	1.94	2.48	3.04	3.60	4.17	4.74	5.31	6.76	8.23	9.70	11.19	14.19
	Multiple	0.74	1.21	1.69	2.20	2.71	3.23	3.76	4.29	4.83	6.20	7.58	8.98	10.40	13.26
12	Single	1.34	2.11	2.90	3.71	4.53	5.36	6.19	7.03	7.87	10.00	12.15	14.31	16.49	20.87
	Multiple	1.15	1.85	2.59	3.34	4.10	4.87	5.66	6.45	7.25	9.27	11.31	13.37	15.46	19.66
14	Single		2.97	4.07	5.20	6.33	7.47	8.63	9.79	10.95	13.89	16.85	19.83	22.83	28.86
	Multiple		2.65	3.67	4.72	5.79	6.87	7.96	9.06	10.17	12.97	15.80	18.66	21.54	27.35
16	Single		3.98	5.45	6.94	8.44	9.95	11.48	13.01	14.55	18.43	22.34	26.27	30.22	38.16
	Multiple		3.59	4.96	6.36	7.78	9.22	10.67	12.13	13.60	17.32	21.07	24.86	28.67	36.35
18	Single		5.15	7.03	8.93	10.86	12.80	14.75	16.70	18.67	23.62	28.61	33.62	38.66	48.78
	Multiple		4.68	6.45	8.25	10.08	11.93	13.79	15.67	17.55	22.31	27.12	31.96	36.83	46.64
20	Single		6.47	8.82	11.19	13.59	16.00	18.43	20.87	23.32	29.47	35.67	41.90	48.15	60.72
	Multiple		5.92	8.14	10.40	12.68	14.99	17.32	19.66	22.02	27.95	33.94	39.97	46.03	58.25
22	Single			10.81	13.71	16.63	19.57	22.53	25.50	28.49	35.98	43.52	51.10	58.71	73.99
	Multiple			10.03	12.80	15.60	18.42	21.26	24.12	27.00	34.24	41.54	48.90	56.29	71.16
24	Single				16.49	19.99	23.51	27.06	30.61	34.18	43.15	52.17	61.23	70.32	88.58
	Multiple				15.46	18.82	22.20	25.62	29.05	32.50	41.18	49.93	58.74	67.59	85.39
26	Single					23.66	27.82	32.00	36.19	40.40	50.98	61.61	72.28	82.99	104.50
	Multiple					22.35	26.35	30.39	34.44	38.52	48.77	59.10	69.50	79.94	100.94
28	Single						32.49	37.36	42.25	47.15	59.46	71.84	84.26	96.73	121.75
	Multiple						30.87	35.58	40.31	45.06	57.02	69.07	81.18	93.34	117.80
30	Single							43.15	48.78	54.43	68.61	82.87	97.17	111.53	140.33
	Multiple							41.18	46.64	52.13	65.92	79.81	93.78	107.80	135.99

$$\text{Volume} = [-0.20296 + 0.150283(\text{DRSQH})^{1/3} + 0.054178(\text{STEM})]^3 \text{ where: } \begin{cases} \text{DRSQH} = \text{DRC square times height} \\ \text{STEM} = 1 \text{ if single, } 0 \text{ if multiple.} \end{cases}$$

Table 15.—Gross cubic foot volume for either single-stem or multiple-stem Gambel oak in Colorado

DRC	Height (feet)											
	4	6	8	10	12	14	16	18	20	25	30	35
Inches	*Cubic feet*											
4	0.09	0.15	0.21	0.28	0.35	0.42	0.49	0.56	0.64	0.82		
6	0.25	0.40	0.56	0.73	0.90	1.07	1.25	1.42	1.60	2.05	2.51	
8	0.49	0.79	1.09	1.40	1.72	2.04	2.37	2.70	3.03	3.86	4.70	5.55
10		1.31	1.80	2.31	2.82	3.34	3.86	4.39	4.92	6.25	7.60	8.96
12			2.70	3.44	4.20	4.96	5.73	6.50	7.27	9.23	11.20	13.19
14				4.81	5.85	6.91	7.97	9.03	10.11	12.80	15.52	18.26
16					7.79	9.19	10.59	12.00	13.41	16.97	20.56	24.16

Volume = $[-0.13600 + 0.145743(\mathrm{DRSQH})^{1/3}]^3$ where: DRSQH = DRC squared times height.

Table 16.—Gross cubic foot volume for either single-stem or multiple-stem bur oak in Wyoming and South Dakota

DRC	Height (feet)													
	4	6	8	10	12	14	16	18	20	25	30	35	40	50
Inches	*Cubic feet*													
4	0.17	0.23	0.29	0.35	0.40	0.46	0.51	0.57	0.62					
6	0.32	0.45	0.57	0.69	0.80	0.92	1.03	1.14	1.25	1.52	1.79			
8		0.72	0.93	1.13	1.32	1.52	1.71	1.90	2.09	2.55	3.01	3.47	3.92	
10		1.07	1.37	1.67	1.97	2.26	2.55	2.84	3.13	3.84	4.54	5.23	5.92	7.29
12			1.90	2.32	2.74	3.15	3.56	3.97	4.37	5.37	6.36	7.35	8.32	10.26
14			2.51	3.07	3.63	4.18	4.73	5.27	5.81	7.16	8.49	9.81	11.12	13.73
16				3.92	4.64	5.35	6.06	6.76	7.45	9.19	10.91	12.61	14.31	17.69
18					5.77	6.66	7.54	8.42	9.30	11.47	13.62	15.76	17.90	22.13

Volume = $[0.12853 + 0.105885(\mathrm{DRSQH})^{1/3}]^3$ where: DRSQH = DRC squared times height.

Table 17.—Gross cubic foot volume for mountain-mahogany in the central Rocky Mountain States

DRC	Basal stems	Height (feet) 4	6	8	10	12	14	16	18	20	25	30
Inches		*Cubic feet*										
4	Single	0.10	0.15	0.21	0.27	0.32	0.38	0.44	0.50	0.56		
	Multiple	0.05	0.09	0.13	0.18	0.22	0.27	0.32	0.36	0.41		
6	Single	0.24	0.37	0.50	0.63	0.77	0.90	1.04	1.18	1.32	1.66	2.01
	Multiple	0.16	0.26	0.36	0.47	0.58	0.70	0.81	0.93	1.05	1.35	1.65
8	Single	0.44	0.68	0.92	1.16	1.41	1.65	1.90	2.15	2.40	3.03	3.65
	Multiple	0.32	0.51	0.71	0.92	1.13	1.34	1.56	1.77	1.99	2.55	3.11
10	Single	0.71	1.09	1.47	1.86	2.24	2.63	3.03	3.42	3.81	4.80	5.79
	Multiple	0.53	0.85	1.18	1.52	1.86	2.20	2.55	2.90	3.25	4.15	5.05
12	Single	1.04	1.59	2.15	2.71	3.28	3.84	4.41	4.98	5.55	6.99	8.43
	Multiple	0.81	1.29	1.77	2.27	2.77	3.28	3.80	4.31	4.83	6.14	7.47
14	Single	1.44	2.20	2.96	3.73	4.51	5.28	6.06	6.84	7.63	9.59	11.56
	Multiple	1.15	1.81	2.49	3.18	3.88	4.59	5.30	6.01	6.73	8.54	10.37
16	Single		2.90	3.91	4.92	5.94	6.95	7.98	9.00	10.03	12.60	15.19
	Multiple		2.44	3.34	4.25	5.18	6.11	7.05	8.00	8.95	11.34	13.76
18	Single		3.70	4.98	6.27	7.56	8.86	10.16	11.46	12.76	16.03	19.31
	Multiple		3.15	4.31	5.49	6.67	7.87	9.07	10.28	11.50	14.55	17.63
20	Single		4.60	6.19	7.79	9.39	10.99	12.60	14.22	15.83	19.88	23.94
	Multiple		3.97	5.41	6.88	8.36	9.85	11.34	12.85	14.36	18.17	22.00
22	Single			7.53	9.47	11.41	13.36	15.32	17.27	19.23	24.14	29.07
	Multiple			6.64	8.43	10.24	12.05	13.88	15.71	17.56	22.19	26.85
24	Single				11.32	13.64	15.96	18.29	20.63	22.97	28.82	34.69
	Multiple				10.15	12.31	14.48	16.67	18.87	21.08	26.62	32.20

Volume $= [-0.13363 + 0.128222(\mathrm{DRSQH})^{1/3} + 0.080208(\mathrm{STEM})]^3$ where: $\left\{ \begin{array}{l} \mathrm{DRSQH} = \text{DRC squared times height} \\ \mathrm{STEM} = 1 \text{ if single, } 0 \text{ if multiple.} \end{array} \right.$

Table 18.—Gross cubic foot volume for either single-stem or multiple-stem hardwoods (willow, boxelder, maple, hawthorn, ash, locust, and cherry) in the central Rocky Mountain States.

DRC	Height (feet) 4	6	8	10	12	14	16	18	20	25	30	35	40	50
Inches	*Cubic feet*													
4	0.04	0.07	0.11	0.14	0.18	0.22	0.26	0.30	0.34	0.44	0.54			
6	0.13	0.21	0.30	0.39	0.48	0.57	0.67	0.77	0.87	1.12	1.37	1.63		
8		0.42	0.59	0.76	0.93	1.11	1.29	1.48	1.66	2.13	2.61	3.09	3.57	
10			0.98	1.26	1.55	1.84	2.13	2.43	2.73	3.48	4.24	5.02	5.79	7.36
12					2.32	2.75	3.18	3.62	4.06	5.17	6.29	7.43	8.56	10.86
14					3.26	3.85	4.45	5.06	5.67	7.20	8.76	10.32	11.89	15.06
16						5.15	5.94	6.75	7.55	9.58	11.63	13.70	15.77	19.95
18						6.63	7.65	8.68	9.71	12.31	14.93	17.56	20.21	25.54
20							9.58	10.86	12.15	15.38	18.64	21.92	25.21	31.83
22							11.74	13.30	14.86	18.80	22.77	26.76	30.77	38.83
24								15.98	17.86	22.58	27.33	32.10	36.89	46.53
26								18.91	21.13	26.70	32.30	37.93	43.58	54.94
28								22.10	24.68	31.17	37.69	44.25	50.83	64.05
30								25.54	28.52	35.99	43.51	51.07	58.65	73.87
35								35.24	39.33	49.59	59.91	70.27	80.66	101.52
40									51.91	65.40	78.96	92.57	106.21	133.60
50									82.36	103.65	125.03	146.47	167.97	211.10

Volume $= [-0.13822 + 0.121850(\mathrm{DRSQH})^{1/3}]^3$ where: DRSQH = DRC squared times height.

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10536

Chojnacky, David C. Pinyon-juniper volume equations for the central Rocky Mountain States. Research Paper INT-339. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 27 p.

Gross cubic foot volume equations are constructed for tree species in pinyon-juniper woodlands of Nevada, Idaho, Utah, Colorado, Wyoming, and South Dakota. Necessary variables for volume prediction are diameter at the root collar (DRC), total height, and a stem count. The equations are recommended for use in large State-wide woodland inventories.

KEYWORDS: woodland, cube root transformation, biweight regression, oak, mountain-mahogany

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April 1985

Survey of Aspen Stands Treated with Herbicides in the Western United States

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RESEARCH SUMMARY

Aspen stands sprayed with herbicide were compared to aspen stands not sprayed in the Western United States. The herbicide 2,4-D mixed at about 2 lb/acre (2.2 kg/ha) with water or diesel was most commonly used. Average number of live aspen trees over 2 inches (5 cm) diameter; stand height, age, and diameter; basal area; and disease incidence were higher in the unsprayed stands. Average number of suckers was generally higher in the sprayed stands. The exception to sufficient suckering occurred where small isolated aspen clones were heavily grazed. There were more grass species and fewer forb species in the understory of the sprayed stands. Grass and total vegetation production was also higher in the sprayed stands. Vegetative cover was greater in the sprayed stands, but organic matter was deeper on the unsprayed plots.

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Survey of Aspen Stands Treated with Herbicides in the Western United States

Roy O. Harniss
Dale L. Bartos

INTRODUCTION

Western aspen (*Populus tremuloides* Michx.) forests are valued by resource managers for the multiple-use values of water, forage, wildlife habitat, and esthetics (DeByle 1981). Aspen stands are being managed by cutting and burning to rejuvenate aspen and to get a better age distribution of stands (Bartos 1981). Herbicide spraying (fig. 1) is now beginning to be used on aspen in areas inaccessible or unsuited for cutting or burning. However, little information is available to the forest manager in the Western United States on what to expect from the use of herbicides or how they could be used to rejuvenate mature aspen stands.

Between 1965 and 1967 in central Utah, 470 acres (190 ha) were repeatedly sprayed with 2,4-D and 2,4,5-T (a total of six times during the growing season) in an attempt to convert the deep-rooted aspen and the associated communities to a more shallow-rooted grass type to increase water production (Robinson 1971). Aspen were virtually eliminated from the site immediately after spraying, and grass production increased approximately 10 times, in part because of aerial seeding. However, other problems arose such as mass slumping, accelerated erosion, and damage to big game habitat. Robinson (1971) indicated that "massive applications of herbicides to aspen and associated plant communities are not recommended at present since the full ecological impact of such treatment is not known." Several years after spraying, suckers 10 ft (3 m) tall were abundant.

In 1958, personnel at the Bridger-Teton National Forest sprayed 9,000 acres (3 645 ha) of sagebrush, which included aspen stringers, on the Upper Green River in western Wyoming. According to Lester (1972), the 2,4-D treatment "eliminated or injured" the aspen and some conifers. Bartos and Lester (1984) examined these aspen stands 22 years later and found abundant aspen trees on the sprayed areas. Forbs were still fewer in number of species, and there were no differences in grasses when compared to unsprayed aspen.

We decided to evaluate aspen stands that were accidentally or purposefully treated with herbicides by comparing the overstory and understory of treated and adjacent untreated stands throughout the Intermountain and Rocky Mountain area.

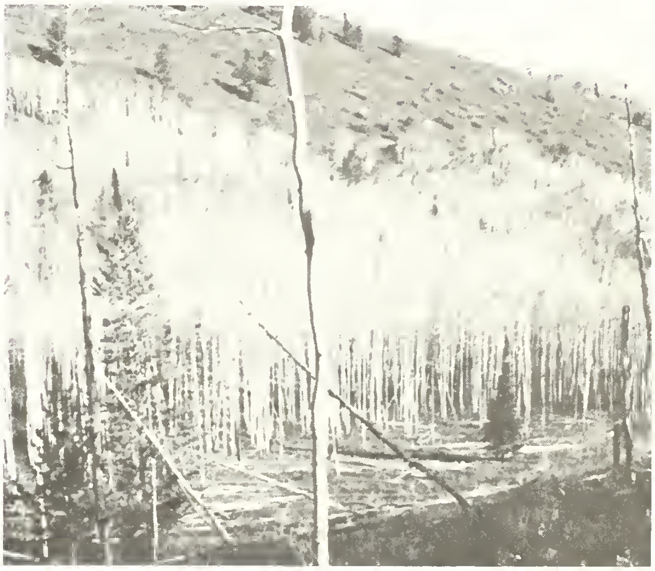

Figure 1.—Herbicide sprayed stand of aspen in southeastern Idaho after 1 year.

METHODS

National Forest personnel in the Western United States identified aspen stands treated with herbicides in conjunction with sagebrush, aspen, or conifer-release spraying projects. Stands were sampled if sprayed and unsprayed comparisons in proximity were about 1 acre (0.4 ha) and had information on the spray treatment. Spray information consisted of herbicide type, rate, carrier (water or diesel fuel), time of year, method of application, and treatment success on target species.

Stands were sampled at two levels of intensity. In stands selected for intensive sampling, 33- by 33-ft (10- by 10-m) plots were placed on the contour of the slope in relatively uniform and representative sprayed and unsprayed vegetation. Environmental attributes recorded were: elevation, aspect, slope percentage, and depth of soil organic layer, melanized layer, and parent material. Tree data determined by species on the entire sample plot consisted of: diameter at breast height (d.b.h.) of live and dead trees over 2 inches (5 cm) d.b.h.; stem count of live and dead reproduction in classes of less than 20 inches (0.5 m) tall, 20 inches to 6.6 ft (0.5 m to 2 m) tall, and greater than 6.6 ft (2 m) tall up to 2 inches (5 cm) d.b.h., and number of stumps and diseased trees (primarily conks). Species numbers, composition, and frequency of the understory were determined by 33 nested frequency frames in each sample plot (U.S. Department of Agriculture 1983). Vegetation litter, rock, and bare ground were estimated from six points per frequency frame on the sample plot. Understory biomass was determined by both clipping and estimating current year's growth, up to 4.9 ft (1.5 m) high, by vegetation categories. Four sets of microplots, were distributed randomly on the 1,076 ft^2 (100 m^2) macroplot. Each set consisted of five circular 5.4 ft^2 (0.5 m^2) microplots clustered so that the biomass of four could be estimated as a percentage of the fifth, which was then clipped. The clipped vegetation was dried at least 48 hours in an oven at 158 °F (70 °C) and weighed for biomass. Percentages of the shrub, grass, and forb components were estimated on all five microplots. The dry weight biomass by vegetation categories is based on 20 microplots per stand. Photographs of the overstory and understory vegetation were taken on all plots.

On the plots sampled less intensively, the tree and environmental data were determined the same as on the more intensively sampled plots. The understory species cover was ocularly estimated on the entire 1,096 ft^2 (100 m^2) plot. The sets of microplots to determine understory biomass were estimated by vegetation categories.

More sprayed than unsprayed stands were sampled because variation was expected to be greater in the sprayed stands. All plots were used in an analysis using the one-tailed t-test for independent means.

RESULTS AND DISCUSSION

We sampled 17 sprayed areas that met our criteria in Idaho, Wyoming, Colorado, and Utah (fig. 2); 34 sprayed plots and 22 unsprayed plots for comparison were sampled (table 1). Sagebrush was the target species for most of the herbicide treatments (table 1). Aspen was sprayed for stand regeneration on four areas and for conifer release on two areas. The herbicide most commonly used was 2,4-D in high volatile butyl ester formulations mixed with water or diesel. The indicated rates of 2 lb/acre (2.2 kg/ha) are possibly higher than that actually applied in the aspen stands associated with sagebrush because of drift and volatilization. Quality control and equipment capabilities would also be factors in nontarget applications. Most of the sagebrush spray projects in which aspen was hit used fixed-wing aircraft in the late 1950's and early 1960's. The rarity of sprayed aspen stands in the 1970's when sagebrush was the target species coincides with the use of helicopter and low-volatile esters. Volatilization effects on nontarget species were reduced markedly when low volatile esters replaced the high volatile esters.

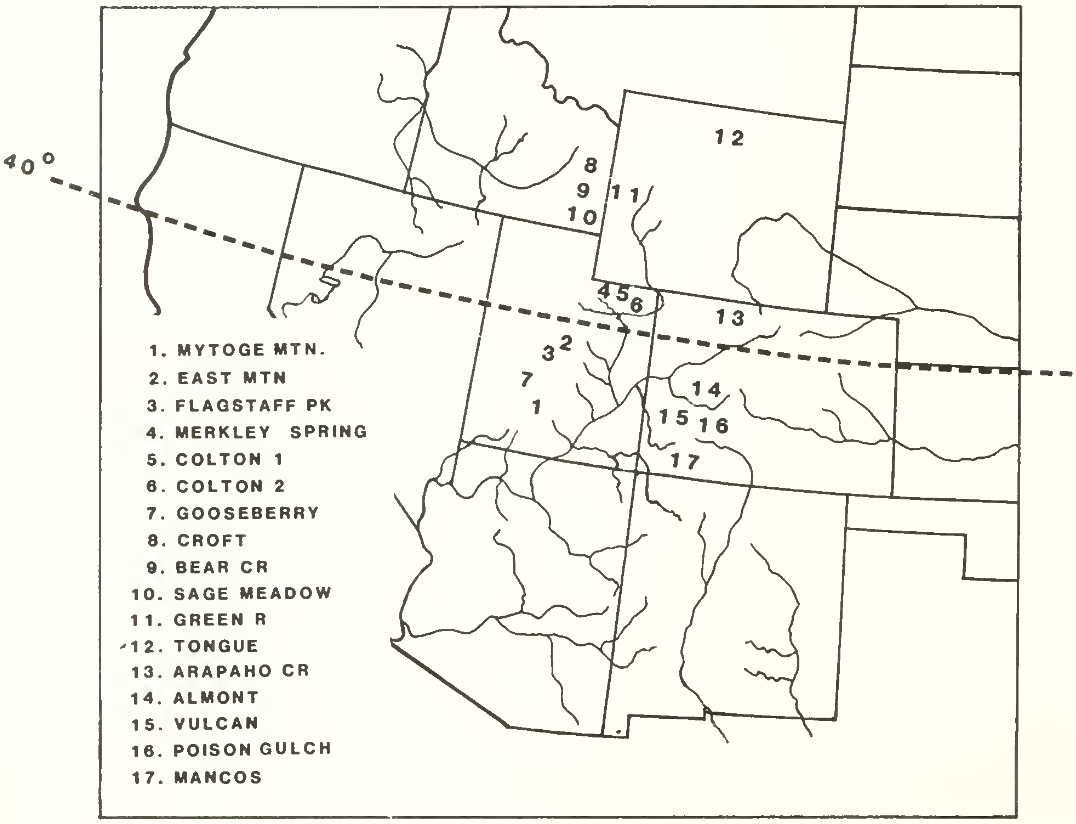

Figure 2.—Locations of herbicide treatments in Western United States.

Table 1.—Herbicide and plot information for I7 aspen stands sprayed with herbicides in the Western United States

		Herbicide						Plot						
Location	Month/year sprayed	Type	Rate[1]		Carrier[2]	Target[3]	Application[4]	Elevation		Slope	Aspect[5]	Spray	Unspray
			kg/ha	*Lb/acre*				*m*	*Ft*	*Percent*		--*Number*--	
1. Mytoge Mountain	6/80	2,4-D	2.2	2	W	SB	Heli	3 017	9,900	9-11	E	1	1
2. East Mountain	7/59	2,4-D	2.2	2	D	SB	FW	3 048	10,000	2-6	SW, NE	2	2
3. Flagstaff Peak	7/68	2,4-D	2.2	2	D	SB	Heli	2 926	9,600	12-14	E	1	1
4. Merkley Spring	6/58	2,4-D				SB	FW	2 621	8,600	2-8	SW	1	1
5. Colton 1	6/64	2,4-D	2.2	2	D	A	Heli	2 621	8,600	5	S	1	1
6. Colton 2	6/64	2,4-D	2.2	2	D	A	FW	2 590	8,500	7-9	SW	2	1
7. Gooseberry	/67	2,4-D/2,4,5T	2.2	2	D	A	Heli	2 621-2 865	8,600-9,400	11-18	All	9	1
8. Croft	6/65	2,4-D	2.2	2	D	SB/A	Heli	2 286	7,500	12-20	NE	1	1
9. Bear Creek	7/82	2,4-D	2.2	2	W	A	Heli	2 530	8,300	22-33	SW-SE	1	1
10. Sage Meadow	7/82	2,4-D	2.2	2	W	A	Heli	2 438	8,000	30-35	E	1	1
11. Green River	/58	2,4-D	2.2	2	D	SB	FW	2 743	9,000	5-17	E	4	3
12. Tongue	7/60/82	2,4-D	2.2	2	D	SB	Heli	2 377	7,800	18	W	2	1
13. Arapaho Creek	/62	2,4-D			W	SB	FW	2 621	8,600	27	NW	1	1
14. Almont	/68	2,4-D				SB	FW	2 865	9,400	37	NW	1	1
15. Vulcan	/81	2,4-D	2.2	2	W	SB	FW	2 895	9,500	24-27	NE	1	1
16. Poison Gulch	/63	2,4-D/2,4,5T	2.2	2	D	SB/A	Heli	3 017	9,900	4-21	SE	3	2
17. Mancos	/77	2,4-D	2.2	2		CR	Heli	2 499	8,200	2-5	N	2	2

[1] Acid equivalent.
[2] W = water, D = diesel.
[3] SB = sagebrush, A = aspen, CR = conifer release.
[4] Heli = helicopter, FW = fixed-wing.
[5] N = north, W = west, S = south, E = east.

Differences occurred between the sprayed and unsprayed stands in the direction to be expected (table 2). Average number of live trees over 2 inches (5 cm) d.b.h., stand height, stand age, stand diameter, basal area, and disease incidence were higher in the unsprayed stands. Average number of suckers was generally higher in the sprayed stands, especially in the over 6.5-ft (2-m) category. The larger variation evident in the sprayed data is due partly to the variation in the number of years since spraying. The range in the number of live trees and stand attributes for the unsprayed stands is about the expected range for aspen forests in the West (Baker 1925; Mueggler and Campbell 1982). However, average stand height, diameter, and basal area appear low for aspen. Perhaps most of the aspen stands associated with sagebrush spraying had drier site condition or poorer stand quality. Suckering on all sprayed stands was generally sufficient for rejuvenating the stand (fig. 3). The exception to sufficient suckering occurred in areas where the aspen clone was small

Table 2.—Tree and stand attributes for 34 sprayed and 22 unsprayed aspen stands

		Sprayed	Unsprayed		Range	
Variable	Units	$\bar{x} \pm s$[1]	$\bar{x} \pm s$	t Prob	Sprayed	Unsprayed
Trees						
Live >5 cm	no/0.01 ha[2]	12.1 ± 13.0	21.0 ± 10.3	0.0046	0-53	9-50
Dead >5 cm	no/0.01 ha	9.0 ± 9.9	6.7 ± 4.3	.1608	0-42	1-16
Stumps	no/0.01 ha	14.5 ± 9.5	3.1 ± 4.2	.0000	0-33	0-14
Suckers						
Live <0.5 m	no/0.01 ha	32.4 ± 59.4	16.5 ± 19.0	.1155	0-212	0-80
Dead <0.5 m	no/0.01 ha	4.0 ± 14.0	1.0 ± 2.5	.1632	0-80	0-11
Live 0.5-2 m	no/0.01 ha	54.8 ± 99.4	23.0 ± 28.9	.0753	0-548	0-121
Dead 0.5-2 m	no/0.01 ha	11.0 ± 11.7	4.9 ± 8.3	.0200	0-37	0-34
Live >2 m-5 cm d.b.h.	no/0.01 ha	39.9 ± 45.1	5.2 ± 12.3	.0005	0-131	0-57
Dead >2 m-5 cm d.b.h.	no/0.01 ha	6.3 ± 9.6	2.1 ± 2.6	.0233	0-42	0-8
Stands						
Height	m	8.7 ± 5.7	12.6 ± 3.4	.0010	0-20	6-20
Age	years	47.7 ± 39.4	83.7 ± 21.8	.0001	0-129	38-117
Average d.b.h.	cm	7.9 ± 5.6	15.0 ± 3.3	.0000	0-19.6	8.4-20.8
Basal area	m^2/0.01 ha	0.102 ± 0.115	0.368 ± 0.161	.0000	0-0.4366	0.1208-0.7399
Disease	P/A[3]	0.029 ± 0.172	0.318 ± 0.477	.0010	0-1	0-1

[1] Average ± standard deviation.

[2] Multiply by 100 for numbers/hectare; 40.47 for numbers/acre.

[3] Presence or absence.

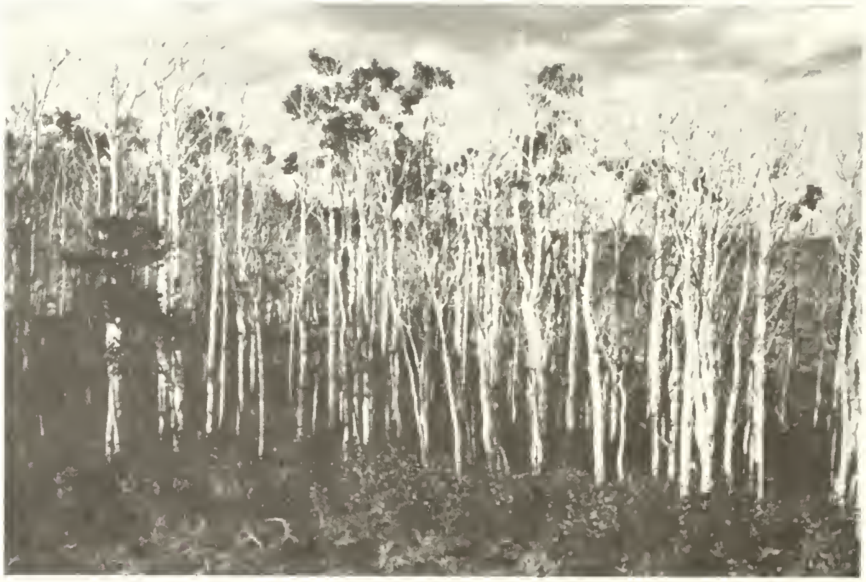

Figure 3.—Abundant regeneration of aspen 3 years after herbicide spraying.

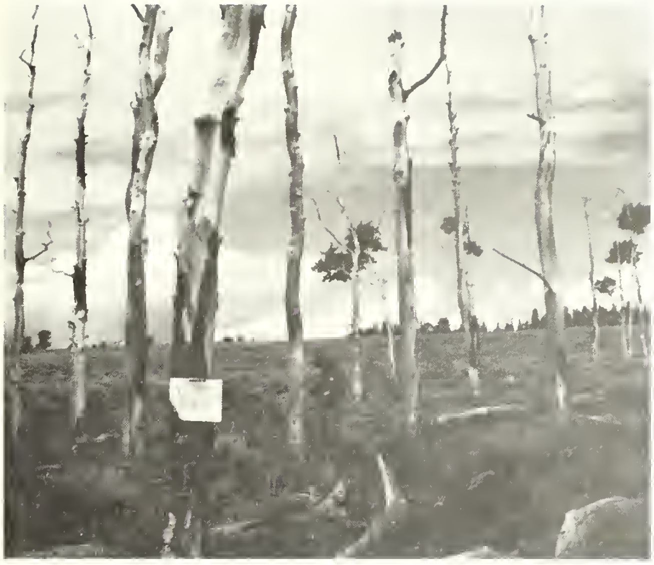

Figure 4.—Isolated aspen stand treated with herbicide with no regeneration of aspen because of heavy grazing by deer and cattle.

(less than 1 acre [0.4 ha]), isolated, and grazed heavily by livestock or big game (fig. 4).

The understory composition had more grass and fewer forbs in the sprayed than in the unsprayed stands (table 3). Grass and total vegetation production was higher in the sprayed than in the unsprayed stands. Shrub numbers were slightly lower in the sprayed stands. Vegetation cover was greater on the sprayed plots, but the organic matter was deeper on the unsprayed plots, possibly due to undisturbed litter from aspen and understory categories. These results agree with expectations of broadleaf herbicide treatments (Anderson 1977). Forbs and shrubs would sharply decrease early while the grasses would increase after spraying. We found that these effects still show 20 or more years after treatment.

Based on the results of our observations and related literature, considerations for the use of herbicides on aspen that appear appropriate are:

1. The purpose for the herbicide treatment should be clearly identified. Aspen regeneration requires less herbicide and different timing than conifer site preparation and release.
2. The use of 2,4-D at a rate of 2 lb/acre (2.2 kg/ha) acid equivalent, low volatile mixed with a water carrier, kills most aspen overstory and initiates aspen regeneration. Lower rates of 1 to 1.5 lb/acre (1.1 to 1.6 kg/ha) may be effective in checking the aspen overstory and initiating suckering. However, this needs to be tested. Dicamba and 2,4-D mixtures have been recommended for *Populus* spp. control (Hamel 1983). These should be used mostly for conifer site preparations. Glyphosate (Roundup®) is being used experimentally in southern Utah in the fall for conifer release in stands with abundant aspen suckers, *Ribes* spp., or both.
3. Herbicides are most effective for stimulating aspen regeneration and conifer site preparation when applied soon after aspen reaches the full leaf stage. For conifer release, herbicides should be applied 1 to 3 weeks before aspen leaf fall to reduce herbicide damage to the conifer.
4. Spraying large openings in the aspen canopy should be avoided to reduce damage to shrubs and forbs, especially where aspen regeneration is the goal. Slight to moderate reductions of shrubs and forbs beneath the aspen should be expected when spraying aspen.

Table 3.—Understory vegetation and soil attributes for 34 sprayed and 22 unsprayed aspen stands

Variable	Units	Sprayed	Unsprayed	t Prob	Range	
		$\bar{x} \pm s$	$\bar{x} \pm s$		Sprayed	Unsprayed
Composition						
Shrub	Percent	22.5 ± 17.7	23.1 ± 14.3	0.4419	1.1-73.9	4.5-56.6
Grass	Percent	47.5 ± 21.3	33.9 ± 15.7	.0063	8.8-86.7	5.8-64.3
Forb	Percent	31.8 ± 17.9	43.0 ± 18.0	.0129	2.6-58.3	9.9-76.2
Weight						
Shrub	kg/ha	296.1 ± 303.1	284.0 ± 255.9	.4390	2.5-1,147.9	29.5-956.0
Grass	kg/ha	585.7 ± 471.3	400.8 ± 449.8	.0764	6.4-1,845.1	17.5-2,018.8
Forb	kg/ha	410.8 ± 343.8	393.4 ± 217.6	.4167	20.8-1,078.9	70.0-832.5
Total	kg/ha	1,292.9 ± 600.6	1,078.3 ± 548.7	.0925	241.9-2,351.2	211.2-2,539.4
Numbers						
Shrub	N/0.01 ha	4.0 ± 1.8	4.9 ± 1.4	.0287	2-9	3-8
Grass	N/0.01 ha	5.7 ± 2.0	5.9 ± 1.8	.4049	3-10	1-8
Forb	N/0.01 ha	11.0 ± 4.6	11.9 ± 4.9	.2354	2-22	4-20
Total	N/0.01 ha	20.6 ± 6.1	22.6 ± 5.7	.1111	12-31	12-34
Cover						
Vegetal	Percent	81.0 ± 16.8	73.6 ± 19.1	.0729	43-100	30-98
Litter	Percent	18.2 ± 16.5	24.4 ± 18.3	.1052	0-65	0-70.0
Rock	Percent	0.6 ± 1.6	1.7 ± 3.3	.0713	0-7	0-11.1
Bare ground	Percent	0.4 ± 0.9	0.8 ± 1.5	.1558	0-3.6	0-5
Soils						
Organic	cm	4.2 ± 1.6	5.8 ± 2.8	.0317	2-8	2-12
A	cm	25.1 ± 14.8	23.5 ± 11.8	.3650	3.8-60	3.8-53
B	cm	40.1 ± 17.4	32.4 ± 12.8	.1204	15-70	15-59

☆U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10534

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Aspen stands sprayed with herbicides had higher numbers of aspen suckers than adjacent unsprayed stands. Understory production was higher due to more grass production in the sprayed stands. While the composition of forb species was lower, the number of grass species was higher on sprayed stands than on unsprayed stands. Vegetative cover was greater on the sprayed plots, but organic matter was deeper on the unsprayed plots. These results agree with expectations of broadleaf herbicide treatments.

KEYWORDS: *Populus tremuloides*, trembling aspen, spraying, understory, 2,4-D, management

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-341

May 1985

Effects of Bifenox, DCPA, and Napropamide on Ectomycorrhizal Development of Conifer Seedlings in Central and Northern Rocky Mountain Nurseries

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CLEMSON UNIVERSITY
SEP 5 1985
PUBLIC DOCUMENTS

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RESEARCH SUMMARY

Postseeding and postgermination treatments with three weed control herbicides (Bifenox, DCPA, Napropamide) at two rates of application caused little reduction of ectomycorrhizal development on 1- and 2-year-old conifer seedlings in Central or Northern Rocky Mountain nurseries. In many cases, herbicide treatment increased ectomycorrhizal development, particularly with DCPA. In general, herbicide treatment effects on ectomycorrhizal development were species and nursery specific.

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INTRODUCTION

Herbaceous weeds are a major problem in Central and Northern Rocky Mountain forest tree nurseries. Weed competition, when uncontrolled, seriously reduces survival and growth of tree seedlings. Weed control practices most often used are fumigation and costly hand or mechanical removal. Hand or mechanical weeding is slow, often unsatisfactory, and increasingly expensive. Soil fumigation is highly effective in reducing the number of viable seeds in the soil but does not prevent reinvasion from nearby areas. Thus, herbicides are attractive as an economical means of reducing weed competition.

Several years of testing pregermination and early postgermination herbicides have shown that several may be useful for weed control in Central and Northern Rocky Mountain nurseries (Ryker 1981). Among these, the herbicides Bifenox (Mobil trade name Modown) [methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate], DCPA (Diamond Shamrock trade name Dacthal) [dimethyltetrachloroterepthalate], and Napropamide (Stauffer trade name Devrinol) [2-(α-naphthoxyl)-N, N-diethylpropionamide] have the potential to reduce hand weeding time by 75 to 95 percent, depending on weed density (Ryker 1981).

Good ectomycorrhizal development is closely related to the ability of conifer seedlings to grow in nursery soils (Trappe and Strand 1969), to survive on harsh sites (Marx 1976), and to successfully afforest or reforest soils lacking in ectomycorrhizal inoculum (Meyer 1973). Some herbicides are reported to reduce growth or development of ectomycorrhizal fungi (Iloba 1974, 1976; Dasilva and others 1977) and to reduce populations of other soil microorganisms (Greaves and others 1976; Ogawa and Yambe 1980). It is possible that herbicides may reduce ectomycorrhizal development on seedlings in treated nurseries, thereby reducing seedling quality. Information on the effects of the above-named three herbicides on ectomycorrhizal development of seedlings in nurseries is lacking and is needed before the herbicides can be approved. This report documents these effects in major forest nurseries of the Central and Northern Rocky Mountains.

MATERIALS AND METHODS

Nursery Locations

The nursery locations represented major conifer-producing nurseries in the Central and Northern Rocky Mountains. These included the U.S. Forest Service nurseries at Coeur d'Alene, ID; Boise, ID (Lucky Peak); Albuquerque, NM; Carbondale, CO (Mt. Sopris); the Montana State Nursery at Missoula, MT; and the privately owned Mountain Home Nursery at DeBorgia, MT.

Experimental Design

The basic experimental design was a randomized block that included the herbicide treatments listed in table 1, and the following seedling species: Austrian pine (*Pinus nigra* Arnold) (AP), blue spruce (*Picea pungens* Engelm.) (BS), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (DF), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) (ES), grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.) (GF), lodgepole pine (*Pinus contorta* Dougl. ex Loud.) (LPP), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) (PP), and western larch (*Larix occidentalis* Nutt.) (WL). Not all species were tested in all locations, but only those normally produced at the respective nursery. The herbicide treatment/species combinations tested at the respective nurseries are shown in tables 3, 4, and 5 in the results section. Each combination, including the untreated control, was represented by three replicate plots. Statistical analysis included ANOVA and Duncan's Multiple Range tests, considering treatment effects and interactions only.

Table 1.—Description of herbicide treatments tested for effects on ectomycorrhizal development of conifer seedlings at major forest nurseries in the Central and Northern Rocky Mountains

Herbicide	Formulation (trade name)	Rate of active ingredient	Timing
		Lb/acre (kg/ha)	
Bifenox	Modown 80% WP[1]	3 and 6 (3.4 and 6.7)	Postseeding
		3 and 6 (3.4 and 6.7)	Postgermination
		3 + 3 (3.4 + 3.4)	Postseeding plus postgermination
DCPA	Dacthal, 75% WP	10.5 and 21 (11.8 and 23.5)	Postseeding
		10.5 and 21 (11.8 and 23.5)	Postgermination
		10.5 + 10.5 (11.8 + 11.8)	Postseeding plus postgermination
Napropamide	Devrinol, 50% WP	3 and 6 (3.4 and 6.7)	Postseeding
		3 and 6 (3.4 and 6.7)	Postgermination
		3 + 3 (3.4 + 3.4)	Postseeding plus postgermination
Control	No treatment	0	—

[1] WP is wettable powder formulation; total active ingredient is based on the manufacturer's recommendation.

Field Procedures

Each plot was bed-wide 4 ft by 3 ft (1.2 m by 0.9 m) along the bed. Each herbicide was applied at two rates (1×, at recommended rate and 2×, at twice the recommended rate), and at two times (postseeding, postgermination of tree seed). In addition, we tested the multiple applications of a 1× postseeding spray followed by a 1× postgermination spray. Herbicides were applied with a pressurized sprayer in a water carrier at a volume equivalent to 85 gal/acre (100 mL/plot). Postsowing treatments were applied within 2 days after sowing; postgermination sprays were applied 28 to 35 days after seedling emergence. Emergence is defined as the time when most seedlings had shed their seed coats. Five herbicide treatments plus a control were represented for each herbicide. A total of 155 treatment combinations (465 plots) were evaluated for ectomycorrhizal development. Other details on the herbicide treatments are available in Ryker (1981).

Sampling Procedures

Thirteen to 15 adjacent seedlings representing each plot were lifted in June 1979 (planted April-May 1978, except at Montana where beds were sown in fall 1977). Seedlings were lifted carefully with a digging fork to avoid root loss and damage. In all cases sample seedlings were adjacent, located two rows from the edge, and well away from the end of the plot. Use of adjacent seedlings (seedling groups) minimized damage to the plots, which were also used for phytotoxicity and weed-control evaluations and standardized general sample location to avoid border effects. Within these confines, the exact positioning of the seedling group was random. Seedling rows were uniform except for occasional missing individuals. All seedlings were placed directly into a plastic bag, with no attempt to separate or clean roots on the site. Plastic bags were put on ice or refrigerated at 34 °F (1 °C) for transport to and storage at the laboratory location. All evaluations were completed within 90 days.

Ectomycorrhizal evaluation procedures.—All ectomycorrhizal evaluations were done with no foreknowledge of plot treatments by three examiners working at least two at a time. Root systems from each of 10 seedlings randomly selected from each plot sample were carefully separated and washed in running water prior to examination. Spot checks on loss of small roots caused by washing indicated such losses were small. Three types of root evaluations were made for each seedling: (1) The total root system was scanned and percentage of ectomycorrhizal roots was estimated to the nearest 10 percent. (2) Excised from each seedling were 10-cm segments of major lateral roots (accumulative if necessary) from the uppermost root system and from the lowermost part of the root system. In each case, the 10-cm segments were cut to include just the first short root nearest the originating major root and to just exclude the last short root. Total number of ectomycorrhizal short roots were counted and recorded separately for the upper and lower 10-cm lengths. (3) Each ectomycorrhizal short root was categorized into an arbitrary morphological type based on external appearance (color, branching habit, etc.). In cases of doubt, thin sections of short roots were examined microscopically to determine if a Hartig net and mantle were present.

Soil Properties

Because of the wide variation in the soils at some of the nurseries, basic properties (soil type, physical makeup, pH, CEC, and organic matter content) were determined for the study site at each nursery (Ryker 1981).

RESULTS

Initial results comparing numbers of ectomycorrhizal short roots on shallow, as opposed to deep, lateral roots indicated no significant differences between treatments. Significantly more short roots occurred on the shallow laterals than on the deep. We therefore discontinued use of deep lateral roots in the evaluation process and present only results using surface lateral roots.

Differences between treatments were small, usually sporadic, and nearly balanced—there were almost as many cases where ectomycorrhizal short roots were more numerous on treated seedlings than on untreated seedlings as there were cases where they were fewer (tables 2, 3, 4). Across the various nurseries no consistent patterns of effects emerged between specific herbicides, species, or treatments. Considering all nurseries, cases of significant interactions within a nursery occurred between all three variables at one location or another (table 5).

Although differences were small, the most consistent related changes were slight reductions in numbers of ectomycorrhizal short roots on Douglas-fir seedlings treated with all three herbicides at the Montana State Nursery, Douglas-fir seedlings treated with Bifenox at the Forest Service nursery at Coeur d'Alene, and slight increases in ectomycorrhizal short roots on lodgepole pine seedlings treated with Bifenox and DCPA at the Forest Service, Lucky Peak nursery (tables 3, 4, 5). Statistical comparisons based on differences in percentage of ectomycorrhizal short roots were almost identical to those based on actual numbers as seen in tables 2, 3, and 4. Therefore, these data have not been presented.

Table 2.—Comparisons of herbicide treatments by mean numbers of ectomycorrhizal short roots (cm) on 10-cm segments of main lateral seedling root, based on 30 samples for each treatment

	Nursery											
	Coeur d'Alene										Albuquerque	
	Ponderosa pine		Engelmann spruce		Douglas-fir		Grand fir		Western larch		Ponderosa pine	
Treatment	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Control (no herbicide)	38.0	9.0	40.6	12.6	30.9	7.4	24.2	11.3	22.0	4.5	42.6	14.6
Bifenox												
Bif. 1×[1], PS[2] + PG[3]	37.3a[4]	9.8	—[5]	—	23.9a**[6]	5.8	28.4a	8.2	—	—	38.1a	13.7
Bif. 1×, PS	46.8b**	11.6	—	—	24.6a**	6.6	26.5a	7.5	—	—	45.2a	10.7
Bif. 1×, PG	40.7a	11.6	—	—	26.6b**	6.4	29.3a	9.9	—	—	46.9b	16.1
Bif. 2×, PS	42.9a	11.4	—	—	22.6a**	4.9	32.1a	8.5	—	—	43.5a	8.8
Bif. 2×, PG	45.5b**	9.6	—	—	30.0b	6.4	27.7a	7.1	—	—	40.6a	13.6
DCPA												
DCPA 1×, PS + PG	—	—	36.2a	9.8	—	—	—	—	23.6a	12.8	45.1a	10.0
DCPA 1×, PS	—	—	47.6b**	8.9	—	—	—	—	21.4a	12.1	44.6a	15.1
DCPA 1×, PG	—	—	37.4a	11.0	—	—	—	—	24.1a	13.1	47.1a	8.9
DCPA 2×, PS	—	—	44.8b	11.6	—	—	—	—	18.5a	5.3	49.6b**	12.1
DCPA 2×, PG	—	—	41.9a	8.4	—	—	—	—	21.1a	3.8	41.8a	13.8
Napropamide												
Nap. 1×, PS + PG	31.2a**	8.9	37.8a	9.5	25.0a**	6.7	27.2a	9.9	—	—	47.9a	9.1
Nap. 1×, PS	36.0a	11.7	38.8a	15.4	26.9a	7.8	25.1a	7.6	—	—	42.8a	15.7
Nap. 1×, PG	42.0b	9.1	36.3a	12.9	27.9a	8.7	26.6a	14.1	—	—	34.1b**	11.1
Nap. 2×, PS	32.9a	9.6	32.3a**	12.1	27.9a	7.3	32.2a	16.7	—	—	38.6b	15.1
Nap. 2×, PG	32.5a	7.1	34.1a	9.8	30.4b	5.1	27.0a	8.9	—	—	45.3a	10.4

---

[1] 1× = applied concentration according to manufacturer's recommendation, 2× = double concentration, for actual concentration of active ingredient (see table 1).

[2] PS = immediately postseeding.

[3] PG = postgermination, usually 4 to 5 weeks after seedling emergence.

[4] Treatments within a single herbicide group and species (down column) that do not share a common subscript letter are significantly different to at least α = 0.05 level, Duncan's multiple range test.

[5] Dash indicates this combination not tested.

[6] ** = treatment differs from appropriate control (head of column) to at least α = 0.01 level, Duncan's multiple range test.

Table 3.—Comparisons of herbicide treatments by mean numbers of ectomycorrhizal short roots (cm) on 10-cm segments of main lateral seedling root, based on 30 samples for each treatment

	Nursery									
	Mount Sopris						Lucky Peak			
	Ponderosa pine		Lodgepole pine		Engelmann spruce		Ponderosa pine		Lodgepole pine	
Treatment	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Control (no herbicide)	37.6	7.1	35.7	6.5	48.7	8.9	35.5	6.3	36.1	7.1
Bifenox										
Bif. 1×[1], PS[2] + PG[3]	37.0a[4]	9.8	34.9a	6.5	—[5]	—	38.6a	5.8	43.1a**[6]	8.4
Bif. 1×, PS	31.4a	7.3	33.0a	6.8	—	—	38.6a	8.6	39.6a	7.0
Bif. 1×, PG	35.2a	9.9	36.3a	5.9	—	—	39.0a	4.8	41.6a**	8.9
Bif. 2×, PS	38.0a	7.7	35.1a	7.0	—	—	33.5a	6.7	41.2a**	7.4
Bif. 2×, PG	33.9a	9.9	31.2b*[7]	5.5	—	—	37.6a	6.9	45.9a**	9.1
DCPA										
DCPA 1×, PS + PG	—	—	—	—	—	—	35.6a	6.3	43.8a**	7.2
DCPA 1×, PS	—	—	—	—	—	—	37.7a	6.5	38.2b	5.8
DCPA 1×, PG	—	—	—	—	—	—	38.2a	6.1	38.3b	7.8
DCPA 2×, PS	—	—	—	—	—	—	38.8a	9.1	41.0b**	9.7
DCPA 2×, PG	—	—	—	—	—	—	37.6a	8.1	44.8a**	8.5
Napropamide										
Nap. 1×, PS + PG	35.2a	9.9	35.4a	7.5	43.3a	6.9	—	—		—
Nap. 1×, PS	33.7a	8.1	37.4a	9.3	43.6a	9.0	—	—	—	—
Nap. 1×, PG	37.0a	7.6	35.7a	7.2	45.6a	11.4	—	—	—	—
Nap. 2×, PS	37.5a	12.4	33.1b	7.3	45.2a	8.2	—	—	—	—
Nap. 2×, PG	34.2a	6.5	34.3a	6.4	46.1a	9.4	—	—	—	—

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[1] 1× = applied concentration according to manufacturer's recommendation, 2× = double concentration, for actual concentration of active ingredient (see table 1).

[2] PS = immediately postseeding.

[3] PG = postgermination, usually 4 to 5 weeks after seedling emergence.

[4] Treatments within a single herbicide group and species (down column) that do not share a common subscript letter are significantly different to at least $\alpha = 0.05$ level, Duncan's multiple range test.

[5] Dash indicates this combination not tested.

[6] ** = treatment differs from appropriate control (head of column) to at least $\alpha = 0.01$ level, Duncan's multiple range test.

[7] * = treatment differs from appropriate control (head of column) to at least $\alpha = 0.05$ level, Duncan's multiple range test.

Table 4.—Comparison of herbicide treatments by mean numbers of ectomycorrhizal short roots (cm) on 10-cm segments of main lateral roots, based on 30 samples for each treatment

	Nursery									
	Mountain Home						Montana State			
	Lodgepole pine		Blue spruce		Austrian pine		Ponderosa pine		Douglas-fir	
Treatment	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Control (no herbicide)	45.1	8.5	55.1	11.4	59.9	7.7	34.3	6.8	28.3	7.7
Bifenox										
Bif. 1×[1], PS[2] + PG[3]	41.6a[4]	7.9	57.9a	11.0	58.1a	7.9	37.1a	10.1	19.0a**[6]	3.6
Bif. 1×, PS	40.3a	6.4	58.0a	11.7	61.5a	8.1	38.4a	8.8	18.8a**	3.7
Bif. 1×, PG	42.3a	7.7	58.9a	14.5	61.9a	9.0	38.9a	10.0	21.4a**	3.8
Bif. 2×, PS	35.8b**	11.6	55.9a	11.8	61.0a	9.8	33.6a	7.1	23.8b**	5.4
Bif. 2×, PG	41.2a	6.5	64.4b**	11.6	60.8a	9.7	36.0a	8.1	16.3c**	8.5
DCPA										
DCPA 1×, PS + PG	47.5a	7.3	52.2a	11.3	56.5a	7.6	33.0a	13.6	21.8a**	6.2
DCPA 1×, PS	42.1b	8.3	57.3a	10.9	62.9a	9.3	35.2b	7.8	21.9a**	6.4
DCPA 1×, PG	36.6c**	12.4	52.1a	12.9	59.4a	9.9	35.2b	6.9	21.0a**	5.3
DCPA 2×, PS	46.0a	8.3	57.6a	12.2	60.5a	8.1	41.3c*[7]	12.5	19.1b**	4.7
DCPA 2×, PG	43.6b	8.7	55.7a	11.6	63.3a	12.1	38.6b	7.8	19.5b**	3.2
Napropamide										
Nap. 1×, PS + PG	—[5]	—	—	—	—	—	37.8a	9.0	20.5a**	3.6
Nap. 1×, PS	—	—	—	—	—	—	38.3a	8.9	24.1b**	4.5
Nap. 1×, PG	—	—	—	—	—	—	34.1a	7.1	23.4a**	7.0
Nap. 2×, PS	—	—	—	—	—	—	36.4a	7.7	20.7a**	5.3
Nap. 2×, PG	—	—	—	—	—	—	35.1a	8.0	20.6a**	4.4

[1] 1× = applied concentration according to manufacturer's recommendation, 2× = double concentration, for actual concentration of active ingredient (see table 1).

[2] PS = immediately postseeding.

[3] PG = postgermination, usually 4 to 5 weeks after seedling emergence.

[4] Treatments within a single herbicide group and species (down column) that do not share a common subscript letter are significantly different to at least $\alpha = 0.05$ level, Duncan's multiple range test.

[5] Dash indicates this combination not tested.

[6] ** = treatment differs from appropriate control (head of column) to at least $\alpha = 0.01$ level, Duncan's multiple range test.

[7] * = treatment differs from appropriate control (head of column) to at least $\alpha = 0.05$ level, Duncan's multiple range test.

Table 5.—Overall interactions between sources of variation and numbers of ectomycorrhizal short roots (cm)

	Nursery					
Source of variation	Coeur d'Alene	Albuquerque	Mount Sopris	Lucky Peak	Mountain Home	Montana State
Within individual source						
Species	**[1]	—[2]	*[3]	**	**	**
Herbicide	**	*	NS[4]	NS	NS	NS
Rate	*	NS	NS	*	NS	NS
Two-way interactions						
Species × herbicide	—	—	—	NS	**	NS
Species × rate	—	*	—	*	*	NS
Herbicide × rate	—	**	—	NS	**	NS
Three-way interactions						
Species × herbicide × rate	—	—	—	NS	NS	**

[1] **Interaction significant, $\alpha = 0.01$, ANOVA.

[2] Dash indicates combination not tested in experimental design.

[3] *Interaction significant, $\alpha = 0.05$, ANOVA.

[4] NS interaction not significant.

Table 6.—Properties of soils at respective nurseries

Nursery	Soil Type	Particle size distribution Sand	 Silt	 Clay	ph	Cation exchange capacity	Organic matter
		------- Percent		-------		meq/100g	Percent
Montana State	Sandy loam	57	30	13	6.9	11.76	2.7
Mountain Home	Loam	40	50	10	5.6	13.67	4.5
Coeur d'Alene	Sandy loam	71	21	8	6.1	6.17	3.1
Lucky Peak	Sandy loam	61	26	13	5.8	7.44	1.7
Mt. Sopris	Sandy loam	55	29	16	6.0	9.87	3.3
Albuquerque	Sandy loam	73	20	7	7.4	5.98	.4

Color and morphology of ectomycorrhizal short roots and other aspects of root structure were similar on the species examined at the respective locations within the limits of variation of sample seedlings. As would be expected, differences occurred in root structure and numbers of ectomycorrhizal short roots on seedlings from different nurseries. Since these differences were not related to the treatments of interest, they were not considered in the analysis. Table 6 documents general soil characteristics at each nursery.

DISCUSSION AND CONCLUSIONS

The lack of strong, consistent relationships between herbicide treatment and numbers of ectomycorrhizal short roots indicate a relatively unpredictable risk factor associated with these herbicides and ectomycorrhizal development. The strong relationships within nurseries, both positive and negative, between herbicide-treated seedlings of particular species and numbers of ectomycorrhizal short roots clearly demonstrate highly individualistic responses. Soil differences between nurseries may contribute to individualistic responses and were likely responsible, at least in part, for between-nursery differences in mycorrhization. However, with regard to mycorrhizae and herbicides, the soil characteristics we measured showed no unusual differences at nurseries where stronger relationships were observed. Accordingly, each combination of herbicide, seedling species, and nursery should be evaluated for possible negative effects.

With the three herbicides investigated here, the most dramatic reductions were from herbicide treatments on Douglas-fir at the Montana State Nursery, which averaged 32 percent. This reduction is probably not enough to cause substantial losses in seedling quality. It does suggest that Douglas-fir may be a sensitive species. The bases for such individualistic responses at a particular nursery are not clear. Because of the lack of explanation, due caution should be exercised with all herbicides.

The lack of strong herbicide-induced reductions and frequent increases in ectomycorrhizal development agree with other experiences (Trappe 1979, 1983; South and Kelley 1972; Ogawa and Yambe 1980; Palmer and others 1980; Greaves and others 1976; Iloba 1974, 1976, 1977; Uhlig 1966). Thus, use of these herbicides for nursery weed control in Central and Northern Rocky Mountain nurseries does not appear to pose high risks to ectomycorrhizal development. The combinations and timing of application tested here could be used in all cases, but with reservations on Douglas-fir. All herbicides and application procedures should be used on this species only with great caution, particularly at the Montana State and Coeur d'Alene nurseries. Even in relatively risky combinations, herbicide use should not be precluded if growth or outplanting performance of seedlings do not suffer.

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*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10539

Harvey, Alan E.; Ryker, Russell A.; Jurgensen, Martin F. Effects of Bifenox, DCPA, and Napropamide on ectomycorrhizal development of conifer seedlings in Central and Northern Rocky Mountain Nurseries. Research Paper INT-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 7 p.

Postseeding and postgermination treatments with three weed control herbicides (Bifenox, DCPA, Napropamide) at two rates of application caused little reduction of ectomycorrhizal development on 1- and 2-year-old conifer seedlings in Central or Northern Rocky Mountain nurseries. In many cases, herbicide treatment increased ectomycorrhizal development, particularly with DCPA. In general, herbicide treatment effects on ectomycorrhizal development were species and nursery specific.

KEYWORDS: weed control, herbicide, ectomycorrhizae, Modown, Dacthal, Devrinol, toxicity, nursery practice

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Research Paper
INT-342

April 1985

Soil Water and Temperature in Harvested and Nonharvested Pinyon-Juniper Stands

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RESEARCH SUMMARY

Tree harvesting increased soil water content, but the effect diminished over 4 years. The mean increase in soil water content was 2 to 4 percent the first year following harvest and 0 to 3 percent after 4 years. Although tree harvesting released soil water previously used by tree species, other biotic and abiotic demands increased. We speculate postharvest increases in wind and solar energy at the ground surface and increased understory transpiration in part explain the decline in soil water content differences between harvested and nonharvested plots over time.

Understory cover increased three to six times following tree harvest on north and west aspects. Understory apparently used soil moisture made available by tree harvesting.

Duff soil microsites had consistently greater soil water than transition or interspace microsites. The duff microsite accumulated soil moisture immediately after tree removal similar to that reported for debris-in-place treatments following chaining. The duff microsite serves as both a mineral nutrient pool and a soil water reservoir. Management should consider the impact of tree harvesting and slash disposal on the nutrient-rich and soil water-rich duff microsite. Destruction of duff during tree removal and burning of slash should not be encouraged.

Soil Water and Temperature in Harvested and Nonharvested Pinyon-Juniper Stands

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INTRODUCTION

The pinyon-juniper woodland of the Great Basin has a mediterranean climate. Soil moisture is depleted in summer and recharged in winter (Gifford and Shaw 1973). Gifford's (1975) water budget for pinyon-juniper woodlands shows a majority of annual precipitation is lost by evapotranspiration and interception. Little runoff or deep percolation occurs.

In environments where water is limiting, natural selection favors those species that compete for soil water and use it effectively. Woodbury (1947) and Plummer (1958) have previously noted the ubiquitous root stems of pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) in woodland stands. Root systems of singleleaf pinyon (*Pinus monophylla*) and western juniper (*Juniper occidentalis*) are composed of surface feeder roots under the tree crown and deeper laterals that occupy the interspace areas between trees (Young and others 1984; Everett 1984). Jeppesen (1977) found western juniper withdrew much of the winter accumulation of soil moisture before associated understory species broke dormancy. Emmerson (1932) found that soil moisture withdrawal by pinyon roots closely followed evaporative demand.

Canopy interception reduces the amount of precipitation reaching the soil surface (Collings 1966). Depth of soil wetting was found to be inversely related to crown density above the sample point (Gifford 1970). Stemflow channels precipitation to soils adjacent the tree stem, but the amount is only a small fraction (0.23 percent) of that intercepted by the tree crown (Young and others 1984).

Removal of trees can increase soil moisture. Gifford and Shaw (1973) studied soil moisture trends in undisturbed pinyon-juniper stands and stands subjected to chaining followed by windrowing and burning of debris. Undisturbed woodlands were found to have the least soil moisture and debris-in-place treatments to have the greatest moisture accumulation. Skau (1964) suggested that tree harvesting of pinyon-juniper stands may considerably increase the water available for forage production. Soil moisture was found to increase over undisturbed stands following felling of alligator juniper (*Juniperus deppena*) and Utah juniper (1.1 and 2.5 percent increase, respectively). The ninefold increase in understory cover on clearcut plots was believed to be the major cause for the small postharvest increase in soil moisture. Everett (1984) found understory cover and yield response to tree harvest was greater on tree-associated soil microsites than in the interspace between trees. This may be the result of increased soil nutrient availability (Everett 1984), improved soil moisture status, or both.

In this study we measured soil matric potentials and percentage soil moisture in tree-harvested and nonharvested pinyon-juniper stands. Soil water measurements were taken in each of the three major soil microsites (duff, transition, and interspace) in each plot. Measurements were taken in what we believed to be the major rooting zone of herbaceous species on the site (Everett 1984). We asked three major questions of our data: (1) Was there a difference in soil water between tree-harvested and nonharvested plots? (2) Was there a difference in soil water among soil microsites? (3) Did soil water vary between 15- and 30-cm soil depths? Finding differences in soil water among tree microsites on harvested plots would suggest the need for cultural prescriptions to protect these microsites during tree harvest.

METHODS

In 1979 three 0.1-ha plots were clearcut of singleleaf pinyon and Utah juniper. Plots occurred on north, west, and south aspects within 2 km of each other on the Shoshone Mountain range of central Nevada. Areas adjacent the tree harvest plots were selected as controls and the three pairs of plots fenced to exclude livestock.

The understory was comprised of perennial grasses Sandberg bluegrass (*Poa sandbergii*), Idaho fescue (*Festuca idahoensis*), squirreltail (*Sitanion hystrix*), and junegrass (*Koeleria cristata*). The ratio of tree cover to grass cover was 28/3, 61/2, and 54/1 percent on north, west, and south aspects, respectively. Pinyon cover exceeded juniper cover in all instances. Elevation at the site was 2 310 m. Precipitation was estimated at 320 mm, 300 mm, 330 mm, and 439 mm for the 4-year study (1980 to 1983). Estimates were the mean value from the two closest weather stations in the same vegetative type 10 km and 70 km distant.

Soils on the site were classified as clayey-skeletal, mixed, frigid, lithic Xerollic Haplargids (USDA 1975). Soils occurred on 14 to 18 percent slopes on north-south ridges. The soil surface was a mosaic of soil microsites, duff, transition, and interspace. Duff microsites occurred under the tree crowns and were defined as those microsites having greater than 0.5 cm depth of continuous needle cover. Transition microsites had discontinuous needle cover less than 0.5 cm deep in a ring at the tree crown perimeter. Interspace microsites had negligible needle cover and occurred between trees.

Soil Water and Temperature Measurements

Matric water potential was recorded on soil microsites in tree-harvested and nonharvested plots. In each plot the soil microsites, duff, transition, and interspace adjacent to two randomly selected trees were chosen for sampling. Gypsum soil moisture blocks (Delmhorst GB-1 cylindrical gypsum blocks) were pressed into the sides of a narrow soil pit at 15- and 30-cm depths. A copper-constantan thermister was placed with each 15-cm deep block to measure soil temperature.

Moisture blocks and thermisters were put in the ground at the time of tree harvest in June 1979 and read from 1980 to 1983. Gypsum blocks remain in good condition for 3 to 5 years under field conditions (Roundy and others 1983). Measurements were taken prior to loss of snow cover (April-May) until late summer (September) at 2- to 4-week intervals. A total of 1,116 soil water and 553 temperature readings were taken during the study. To facilitate comparisons between sample dates, most measurements were taken from 6 to 8 a.m.

Thermister readings in microvolts were converted to temperature readings (°F) using water bath calibration curves. Water content measurements in resistance (ohms) were converted to bars of soil matric potential using the equation provided by Roundy and others (1983): bars = $([4.253 * 10^{-4} \text{ ohms}] + 0.2)$. Because total soluble salts were low (0.1 to 0.4 S dm^{-1} [1 bar]: Everett 1984) matric potential closely approximates total soil water potential.

The effective measurement range of gypsum blocks is 0 to -15 bars; a range exceeded under a semiarid climate. To expand the range of our soil measurements we calibrated moisture block resistance readings (ohms) to percentage soil moisture in laboratory tests. Moisture blocks were placed in glass jars (27 replicates) filled with soils from the site. Soils were wetted, the jars sealed and heated at 100 °C for 24 h to vaporize the water, and then allowed to cool. Moisture block resistance and percent soil moisture were recorded after a 24-h equilibration period. Lids were then removed, a portion of the soil water driven off by heating, jars resealed, and the procedure repeated. The derived exponential calibration curve (soil moisture = $83.796\ e^{-0.434 \text{ ohms}}$) had a coefficient of determination (r^2) of 0.85. The curve is asymptotic above saturation and ineffective in measuring increased soil water content.

Understory cover was recorded on the harvested and nonharvested plots from 1979 to 1983. Each plot had five permanent transects 20 m in length at 5-m intervals across slope. A 50-cm square sampling frame was laid down every 1 m, and understory crown cover was estimated by Daubenmire's canopy coverage method (1959).

Analysis

Soil moisture readings for a given year were analyzed by t-tests of differences. The experimental unit was the mean of two values for a given soil depth or the mean of four values for a given microsite on a given date. There were six to 11 replicates to test for differences in soil moisture between harvested and nonharvested plots and among soil microsites in a given year. There were four replicates over time (1980 to 1983) to test for differences among aspects. Each of the four replicates represented the mean of 30 to 60 observations. The reader is cautioned that, because aspect plots were not replicated over space, results may not apply to the population from which sites were drawn.

RESULTS AND DISCUSSION

Both soil water content and soil temperature increased following tree harvesting. The increase was short lived as understory cover increased rapidly. Soil moisture content of soil microsites was uniform on nonharvested plots, but variable on harvested plots.

Matric Water Potential

Soil water content was greater on tree-harvested than nonharvested plots, but the difference declined over 4 years (table 1). Soil moisture was generally 2 to 5 percent greater on harvested plots but varied from 0 to 12 percent among sites and years. Results were somewhat higher than Skau's (1964) report of a 1 to 2 percent increase in soil water following tree harvest. But values were within the 0 to 15 percent increase in soil moisture reported by Gifford (1975).

Contrary to our expectations, we found soil water to be significantly ($p = 0.1$) greater on the south than north harvest plot in 1980 and 1981. The trend reversed itself in 1982 and 1983. Soil water patterns varied from year to year (fig. 1). Soil water rapidly declined with the summer drought in early June and increased following precipitation in late August or September. Soil water content was consistently lower on nonharvested plots than harvested plots throughout the growing season. Differences in soil water between harvested and nonharvested plots were least in the fourth year of study.

Matric water potentials were near zero in early spring under snow cover but rapidly exceeded -15 bars. The mean date for soil water to exceed -15 bars was June 29 on harvested plots and June 19 on nonharvested plots. Matric potentials less than -15 bars occurred 19 days later on harvested than nonharvested plots the first year following tree harvest. This relationship varied among years, and by the fourth year matric potentials less than -15 bars occurred 5 days earlier on harvested plots.

Soil water content was greater at the 30 cm than at the 15 cm depth, but not significantly so. Mean soil

Table 1.—Percentage soil moisture for harvested and nonharvested plots on south, west, and north aspects (means over all microsites, depths, and sample dates)

Aspect	1980 H	1980 N[1]	1981 H	1981 N	1982 H	1982 N	1983 H	1983 N
	Percent soil moisture							
South	22.6*[2]	17.8	22.8**	9.5	18.8**	13.2	18.6^{ns}	18.6
West	20.2^{ns}	18.4	14.7*	10.4	17.1^{ns}	17.1	20.5^{ns}	18.9
North	19.9^{ns}	15.7	11.0^{ns}	9.6	19.1^{ns}	16.7	21.3^{ns}	18.2

[1] H = harvested plot, N = nonharvested plot.
[2] *, ** = significant differences (p = 0.1, 0.05) between harvested and nonharvested plot values.
ns = nonsignificant difference.

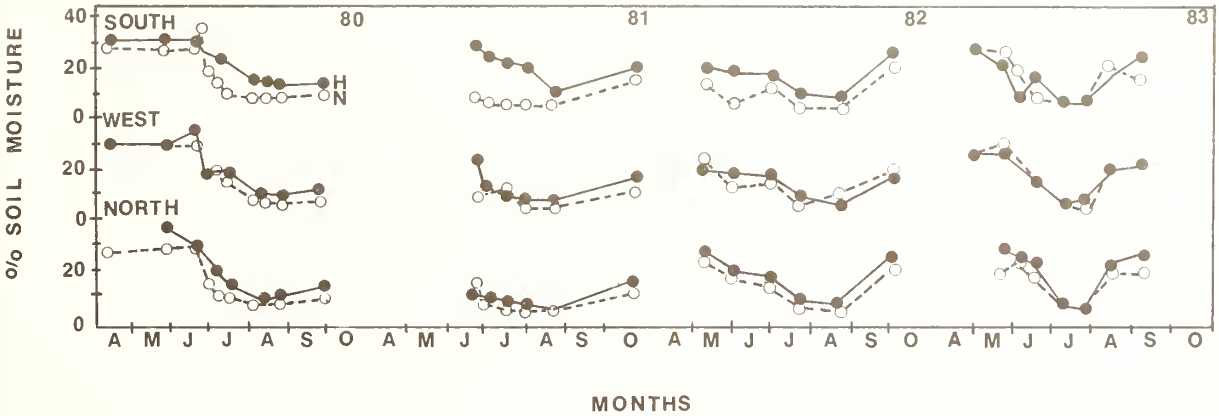

Figure 1.—Soil water content in tree-harvested (H) and nonharvested (N) plots on south, west, and north aspects in 1980, 1981, 1982, and 1983.

Table 2.—Mean percentage soil moisture on harvested and nonharvested plots by year and soil microsites

Type of plot	1980 D	1980 T	1980 I[1]	1981 D	1981 T	1981 I	1982 D	1982 T	1982 I	1983 D	1983 T	1983 I
	Percent soil moisture											
						South						
Harvest	27.5^{a}[2]	18.9^{b}	20.5^{ab}	25.6^{a}	19.5^{b}	21.7^{ab}	18.8^{a}	17.9^{a}	18.2^{a}	20.7^{a}	18.1^{a}	20.8^{a}
Nonharvest	17.0^{a}	17.8^{a}	14.5^{a}	9.5^{a}	10.2^{a}	9.5^{a}	12.0^{a}	14.7^{a}	11.6^{a}	19.0^{a}	19.0^{a}	18.9^{a}
						West						
Harvest	24.1^{a}	15.2^{b}	20.4^{ab}	17.9^{a}	9.4^{b}	13.6^{b}	17.1^{a}	15.8^{a}	17.8^{a}	19.5^{a}	19.7^{a}	19.5^{a}
Nonharvest	18.0^{a}	18.8^{a}	18.0^{a}	7.7^{a}	10.3^{a}	8.4^{a}	14.0^{b}	20.3^{a}	16.7^{b}	20.9^{a}	21.4^{a}	20.4^{a}
						East						
Harvest	25.3^{a}	14.5^{b}	14.0^{b}	15.2^{a}	9.3^{b}	8.9^{b}	21.1^{a}	18.0^{a}	18.2^{a}	22.5^{a}	20.7^{a}	21.0^{a}
Nonharvest	19.9^{a}	14.3^{a}	15.5^{a}	10.1^{a}	7.1^{a}	10.5^{a}	16.7^{a}	15.6^{a}	17.8^{a}	19.1^{a}	17.3^{a}	18.2^{a}

[1] D = duff microsite, T = transition microsite, and I = interspace microsite.
[2] Microsites on the same plot (row) with different superscripts are significantly (p = 0.05) different.

water (all years and aspects combined) on harvested plots was 17.7 percent at 15 cm and 19.6 percent at 30 cm. Mean soil water on nonharvested plots was 14.9 percent at 15 cm and 15.3 percent at 30 cm. Relatively more moisture was available in subsurface horizons for deep-rooted species. Lateral roots from juniper or pinyon (Emmerson 1932; Young and others 1984; Everett 1984) occur in subsurface horizons. The long-term capability of the trees to capture subsurface soil moisture and associated nutrients is indicated by nutrient accumulation under the tree crowns (Barth 1980; Everett 1984).

Duff soil microsites had greater soil water content than interspace or transition microsites on harvested plots (table 2). The duff microsite accumulated soil moisture much like the debris-in-place microsite created by chaining and windrowing (Gifford 1982). Differences among soil microsites on harvested plots declined over years. There were no significant differences in soil water content among microsites on nonharvested plots.

Soil Temperature

Mean soil temperature at the 15-cm depth was always greater on harvested than nonharvested plots during the growing season (table 3). The obvious loss of tree shade and recorded higher soil temperatures in harvested plots suggest increased solar radiation to the soil surface. Gifford (1973) reported triple the amount of wind on sites where pinyon and juniper trees had been removed. Evaporative demand on tree-harvested sites would be intensified by both solar and wind increases. Differences in soil water between harvested and nonharvested treatments would be diminished.

Table 3.—Soil temperature at 15-cm depth on harvested and nonharvested plots (mean of all soil microsites and years)

South		West		North	
H	N[1]	H	N	H	N
°C					
15.8^{a}[2]	13.1^{b}	13.3^{a}	12.3^{b}	13.6^{a}	11.4^{b}

[1] H = harvested plots, N = nonharvested plots.

[2] Harvested and nonharvested plot values for the same aspect that have different superscripts are significantly (p = 0.05) different.

We found no difference in soil temperature among soil microsites in harvested plots, but surface temperatures increased from the duff to the interspace in nonharvested plots (table 4). Grasses in interspace microsites on nonharvested plots are faced with both low soil water and high soil temperature regimes. Reduced understory cover in the interspace microsites has been previously reported (Everett 1984).

Table 4.—Soil temperature at 15-cm depth for soil microsites on harvested and nonharvested plots (mean for all aspects and years combined)

Harvest			Nonharvest		
D	T	I	D	T	I[1]
°C					
11.0^{a}[2]	12.3^{a}	13.3^{a}	13.8^{c}	14.3^{b}	14.0^{a}

[1] D = duff, T = transition, and I = interspace microsites.

[2] Microsite values with different superscripts in harvested or nonharvested plots are significantly (p = 0.05) different.

Understory Cover

Grass cover significantly ($p = 0.05$) increased from 5 to 15 percent on the north aspect and from 2 to 13 percent on the west aspect following tree harvest. Cover on the south aspect was initially low and did not exceed 4 percent after 4 years. Soil water was greatest on the south slope. Perhaps reduced transpiration on this sparsely vegetated site caused this anomaly. Soil water differences between harvested and nonharvested plots were least on north and west aspects where the increase in understory cover was greatest. We observed that duff microsites with a deep needle cover inhibited understory establishment.

CONCLUSIONS

Tree harvesting increases soil water, but only temporarily. Transpiration from released understory and evaporation from the soil surface are speculated to rapidly reduce initial postharvest soil water levels. Soil water is relatively greater under the duff surrounding cut stems. These microsites are also nutrient-rich and provide a favorable environment for understory growth at their periphery. Where understory is associated with the duff microsite, these microsites should be protected from destruction during tree harvesting and slash disposal. Because duff tends to inhibit establishment of understory species, this recommendation is not valid when tree harvest sites are to be seeded.

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Soil water and temperature initially increased following tree removal. The duff soil microsite accumulated soil moisture and the transition microsite at the edge of the duff became depleted. The south aspect had the greatest increase in soil moisture and the least understory cover. Differences in soil moisture between harvest treatments declined over the 4-year study as understory cover increased.

KEYWORDS: soil water, pinyon, juniper, Great Basin, tree harvest

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Research Paper
INT-343

June 1985

Natural Regeneration in Intermountain Spruce-Fir Forests—A Gradual Process

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CLEMSON UNIVERSITY
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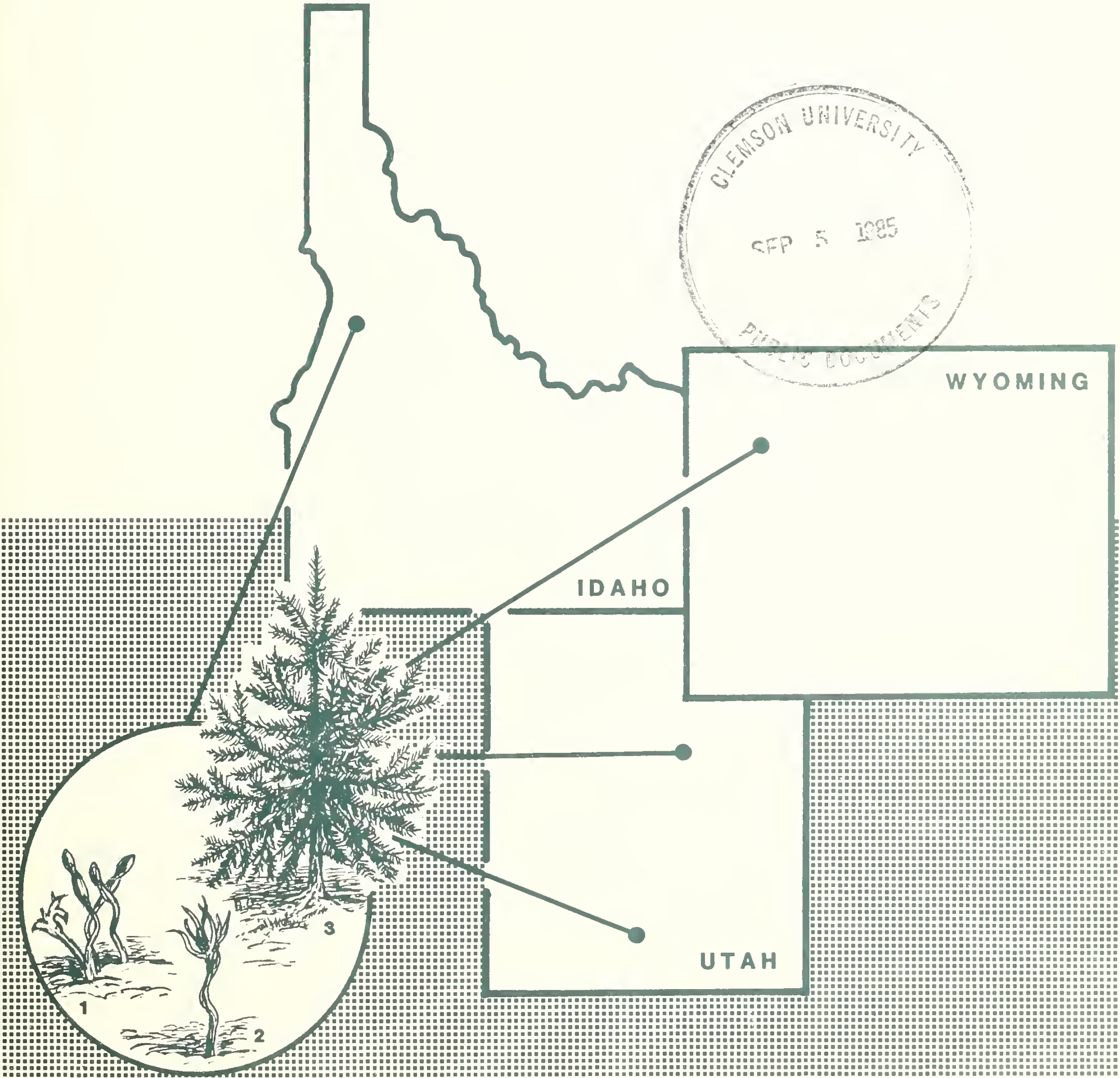
PUBLIC DOCUMENTS



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RESEARCH SUMMARY

This study evaluated the effects of five harvest cutting-site preparation treatments on regeneration establishment in Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) forests of the Intermountain West. The five treatments—clearcut-scarify, clearcut-broadcast burn, clearcut-no site preparation, partial cut-scarify, and partial cut-no site preparation—were evaluated after 5 and 10 years to determine the amount and character of subsequent regeneration at four locations in Utah, Idaho, and Wyoming. In absolute terms, partial cutting treatments tended to favor the establishment of the shade-tolerant spruce and fir more than did clearcutting. Mineral soil proved more favorable for seedling establishment on the lower elevation sites in Idaho and Wyoming, while duff proved more favorable in the severe climate of high elevation sites in Utah. Even though there were many germinates, high seedling mortality throughout the 10 years resulted in relatively slow accumulation of established seedlings. For example, an average of only 10 percent of the seedlings present 5 years after harvest survived until year 10.

These results support the concept that reaching full stocking in this forest type by natural regeneration is a gradual accumulative process, and that supplemental planting will usually be needed if full stocking must be reached in a shorter time.

ACKNOWLEDGMENTS

We thank the Timber Management staff of the Forest Service Intermountain Region and the staffs of the Payette, Teton (now Bridger-Teton), Uinta, and Dixie National Forests for their parts in the conduct of this study. Also, we thank Arthur L. Roe (Intermountain Research Station, retired) for designing the original cutting methods trials that provided the conditions needed for this study, Dr. Robert D. Pfister (Montana Forest and Conservation Experiment Station, University of Montana) for his support and help in classifying the ecological habitat types of the study areas, Al Dahlgreen (Intermountain Region, retired) for his help in establishing and conducting the original study, Orville Engelby (Intermountain Region silviculturist) for his continuing advice and support of this study, and Joyce Schlieter (Intermountain Research Station) for statistical help in completing this paper.

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Natural Regeneration in Intermountain Spruce-Fir Forests—A Gradual Process

Carl E. Fiedler
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INTRODUCTION

Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) forests blanket a major portion of the upper elevations of the Rockies. In the Intermountain section of the Rockies, this forest type comprises a large proportion of the timber resource. However, before the middle of this century, there was little harvest cutting in spruce-fir forests. Beetle (*Dendroctonus rufipennis* [Kirby]) epidemics in the 1950's caused substantial mortality in these forests, and managers responded with harvest cuttings aimed both at salvaging mortality and removing beetle-susceptible host trees. Because of the short time managers had to respond to the beetle, harvest cuts were seldom accomplished in a well-defined silvicultural framework. Many of these harvested areas failed to regenerate or were slow in regenerating.

Natural regeneration failures in these sanitation-salvage cuttings, as well as on more conventionally harvested areas, pointed out the need for more information about the regeneration processes in spruce-fir forests. Subsequent studies assessed the extent of the problem and delineated some of the apparent causes of regeneration failures. Results of these studies (Roe and Schmidt 1964; Roe and others 1970) pointed out the importance of seedbed, local environment, and seed supply in determining the ultimate success or failure of natural regeneration in this forest type. The factors associated with this triumvirate needed to be built into a silvicultural framework that could be tested. This need prompted the U.S. Department of Agriculture, Forest Service, Intermountain Region and Intermountain Research Station to enter into a joint study effort aimed at determining the long-term effects of several combinations of harvest cutting and site preparation methods on natural seedling establishment. To make the results as applicable as possible, the study was established on four widely separated areas of the Intermountain Region—the Payette, Teton (now Bridger-Teton), Uinta, and Dixie National Forests.

The primary objectives of this study, started in 1967, were to:

1. Evaluate the growth response of advance understory trees to release following clearcutting and partial cutting.
2. Evaluate the effects of five harvest cutting-site preparation treatments on natural regeneration establishment.

McCaughey and Schmidt (1982) reported the results of the first objective. This paper reports the results of the second objective based on the 5-year and 10-year remeasurements of the four study areas.

METHODS

Five harvest cutting-site preparation treatments, with two replications, were installed on each of four study areas in 1967. The overall study design was a 4 × 5 factorial, with two replications per cell.

Source of variation	Degrees of freedom
Forests	3
Treatments	4
Interaction (forests × treatments)	12
Error	20
Total	39

The five treatments were:

1. Clearcutting with dozer scarification (CCS)
2. Clearcutting with broadcast burning (CCB)
3. Clearcutting with no site preparation (CCO)
4. Partial cutting with dozer scarification (PCS)
5. Partial cutting with no site preparation (PCO)

Each treatment was applied to two rectangular (10- by 20-ch) 5-acre units for a total of 10 treatment units per study area. Twenty 1-milacre regeneration plots (6.6 by 6.6 ft) were established in each treatment unit for a total of 40 plots per treatment. Ten plots were randomly established in each 5-acre unit by superimposing a grid over the treatment unit map and randomly selecting coordinate pairs (fig. 1). Because randomly established plots did not always represent the assigned site preparation treatment, a second plot was subjectively located on the closest representative seedbed to each random plot. For example, on treatment units receiving dozer scarification, subjectively located plots were established on the closest area of mineral soil large enough to accommodate a milacre plot.

Seedling numbers were recorded by species in two categories—first-year seedlings and 2-year and older

PLOT NO	AXIS X	AXIS Y
1	5	14
2	3	6
3	2	18
4	9	17
5	8	9
6	2	13
7	7	3
8	4	18
9	2	4
10	5	9

NOTE X & Y VALUES ARE FROM RANDOM NUMBER GENERATOR

R - RANDOMLY LOCATED PLOT

S SUBJECTIVELY LOCATED PLOT

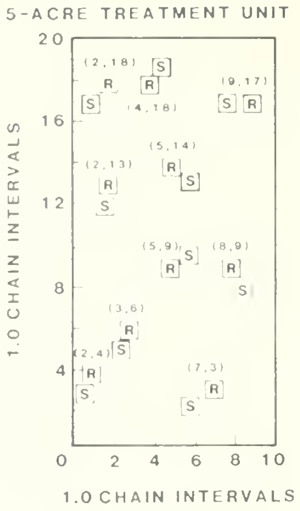

Figure 1.—Schematic example of a treatment unit map illustrating milacre plot locations.

seedlings—for each plot 5 and 10 years after treatment. Because no seedlings were yet 5 years old at the 5-year postharvest measurement, the number of 5-year and older seedlings was recorded for each plot at year 10 only. Each plot was also classified as to habitat type and seedbed surface.

Study Areas

The overall study area extended approximately 425 north-south air miles from southern Utah to south-central Idaho and 325 east-west air miles from south-central Idaho to western Wyoming. The four study areas were located on the Payette National Forest in Idaho, the Teton National Forest in Wyoming, the Uinta National Forest in central Utah, and the Dixie National Forest in southern Utah (fig. 2).

Payette National Forest.—The Payette study area is near Cloochman Creek on the McCall Ranger District, about 6,000 ft elevation with a west to southwest exposure. Slopes range from 0 to 30 percent and average around 10 percent.

Soils are generally sandy loams of granitic origin, moderately to well drained, and slightly acid. Some of the cutting units are bisected by small streams and contain boggy areas.

Composition (by volume) of the virgin stand was 77 percent Engelmann spruce, 18 percent subalpine fir, and 5 percent lodgepole pine (*Pinus contorta* Dougl. ex Loud.). The mature stand was over 200 years old at the time of cutting.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
129.0	29.0	7.0

Individual point samples ranged from 0 to 250 ft^2 of basal area per acre. Remaining basal area within the clearcuts was due to residual advance regeneration. Partial cut treatments were individual tree selection cuts.

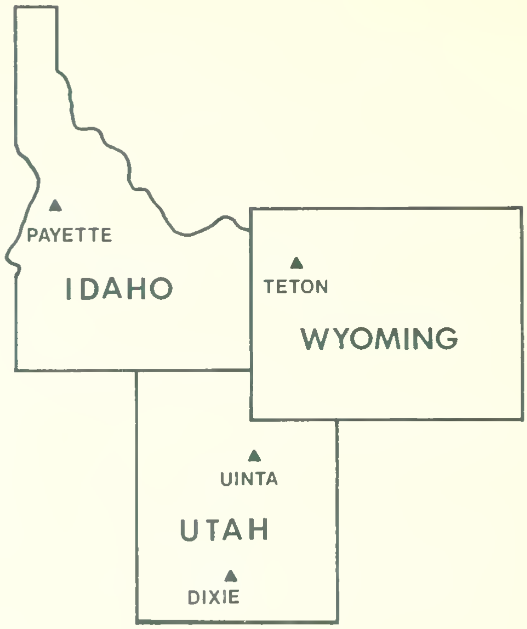

Figure 2.—Location of spruce-fir natural regeneration study areas in the Intermountain West: Payette, Teton, Uinta, and Dixie National Forests.

Three habitat types (h.t.'s) are represented on the area (Steele and others 1981):

Dry	-	*Abies lasiocarpa/Xerophyllum tenax* h.t., mostly *Vaccinium scoparium* phase.
Moist	-	*Abies lasiocarpa/Xerophyllum tenax* h.t., mostly *Vaccinium globulare* phase.
Wet	-	*Abies lasiocarpa/Calamagrostis canadensis* h.t., *Ligusticum canbyi* phase.

Teton National Forest.—The Teton study area is in Teton County, WY, near East Leidy Creek on the Gros Ventre Ranger District at approximately 8,600 ft elevation. The study area faces north and ranges in slope from 0 to 50 percent, with occasional pitches to 70 percent.

Soils are derived from Mesozoic sedimentary rock—primarily limestone, sandstone, and shale. Moisture is adequate at all times of the year, and some areas have excessive soil moisture for ideal growing conditions, as evidenced by the increase of *Equisetum*. Drainage of the area varies from poor to good.

The Teton has the largest variety of species found on any of the study areas. Stand composition (by volume) at the time of harvest was 85 percent Engelmann spruce, 8 percent subalpine fir, 3 percent lodgepole, 3 percent limber pine (*Pinus flexilis* James), and 1 percent Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco).

Stand age of the mature overwood at the time of cutting was between 200 and 300 years old. The general stand condition was good, with only minor bark beetle problems in some of the windthrown spruce.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
132.0	82.0	1.0

Individual point samples ranged from 0 to 280 ft^2 of basal area per acre. The clearcut basal area value was due to residual advance regeneration. Partial cut treatments were individual tree selection cuts.

Three habitat types were mapped on the study site (Steele and others 1983):

Dry	-	*Abies lasiocarpa/Vaccinium globulare* h.t.
Moist	-	*Abies lasiocarpa/Actaea rubra* h.t.
Wet	-	*Abies lasiocarpa/Streptopus amplexifolius* h.t.

Uinta National Forest.—The Uinta National Forest study area is in Wasatch County, UT, on the Heber Ranger District. The plots are on a northerly aspect at 9,500 ft elevation, with slopes ranging from 10 to 30 percent.

Soils are generally well drained on the upper slopes, with soil moisture increasing toward the base of the study area. Small intermittent streams bisect the area.

Stand composition (by volume) was 95 percent Engelmann spruce and 5 percent subalpine fir. General stand condition was good with minimal windthrow and light bark beetle damage.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
146.0	109.0	42.0

Individual point samples ranged from 0 to 230 ft^2 of basal area per acre. The large basal area value in the clearcuts was due to advance regeneration left on the site. Partial cut treatments were group selection cuts; that is, small half-acre clearcuts scattered throughout the 5-acre treatment block.

One habitat type was found on the area—*Abies lasiocarpa/Berberis repens* h.t., *Berberis* phase (Pfister 1972).

Dixie National Forest.—The Dixie study units are in Garfield County, UT, on the Aquarius Plateau of the Escalante Ranger District at 10,300 ft elevation on nearly level terrain.

Soils are glacial deposits overlaying basalt flows. Soils are gravelly, clay, and sandy loams, 12 to 21 inches deep, with pH values of 5 to 6.

Stand composition (by volume) of the mature forest was 90 percent Engelmann spruce, 10 percent subalpine fir, and a few small scattered aspen (*Populus tremuloides* Michx.) clones. Overstory Engelmann spruce were all-aged, while subalpine fir were uneven-aged but not all-aged (Hanley and others 1975). General condition of the mature stand was good, but many snags indicated past beetle attacks. Recent bark beetle activity was light.

Average basal areas, in ft^2 per acre, remaining after the harvest cuttings were:

Uncut forest	Partial cut	Clearcut
141.0	40.0	6.0

Individual point samples ranged from 0 to 210 ft^2 of basal area per acre. Advance regeneration accounted for the clearcut basal area. Partial cut treatments were group selection cuts; that is, small half-acre clearcuts scattered throughout the 5-acre treatment block.

One habitat type, *Abies lasiocarpa/Ribes montigenum* h.t., *Ribes* phase (Pfister 1972), was found on the study area.

Treatment Establishment

The original intent of the study was that harvest and site preparation on each of the four forests would be accomplished the same year, 1967. However, because of weather and other problems, some exceptions to the original schedule occurred:

Payette—Burning was unsuccessful in November 1967; it was completed in September 1968.

Uinta—Three scarification treatments were completed in 1968 and one in July 1969.

Dixie—All units scheduled for burning were completed in fall 1968, a year after logging.

Otherwise, all treatments were completed in 1967.

Data Analysis

We described natural regeneration establishment with percentage milacre stocking and seedling density per acre. Stocking and density of seedlings 2 years of age and older are compared between treatments and within treatments for the 5-year and 10-year periods after harvest. First-year seedlings were not included because of the extremely high mortality rate in this age class (Noble and Alexander 1977; Alexander 1984). Because 5-year-old seedlings in spruce-fir forests are considered established from the standpoint of environmental factors (Noble and Ronco 1978), stocking and density of seedlings 5 years of age and older were also compared between treatments for the 10-year postharvest measurement.

Wide variability in both stocking levels and seedling counts made data transformation necessary before analysis could proceed. Because stocking is expressed as a proportion (percent), the arcsin transformation was selected to stabilize the variance. The transformation $\sqrt{\text{density} + 1}$ was used to stabilize variance of density data. This particular form of the square root transformation was chosen because some seedling counts were zero (Snedecor and Cochran 1967).

Initially, pooled data from all forests were analyzed to determine if stocking and density varied significantly between forests. Analysis of variance methods showed both stocking and density varied significantly ($\alpha = 0.05$) between forests. Therefore, further analysis was conducted on a forest-by-forest basis.

The following techniques were used to analyze natural regeneration data from individual forests.

Stocking: The test for binomial proportions was used to analyze within-treatment changes in stocking from the fifth to the 10th year after harvest. Stocking between treatments and stocking of random versus subjective plots were also compared using this technique.

Density: The Student's t-test was used to analyze within-treatment changes in seedling density from the fifth to the 10th year after harvest. This method was also employed to test density between treatments and between randomly and subjectively located plots. An approximate t-test was used in cases where variances were unequal.

RESULTS AND DISCUSSION

Results of this study provide insight into the post-harvest natural regeneration of high-elevation spruce-fir forests and help explain the frustration experienced by many managers in this forest type. The "wave" of natural regeneration that often follows harvest in lodgepole pine, ponderosa pine, and western larch forests is not a common phenomenon in these spruce-fir forests. Instead, a slow accumulation of surviving seedlings appears the normal pattern of restocking on cutover areas. The following sections describe this process in the framework of different silvicultural treatments for the first 10 years after harvesting.

Stocking—Between Treatments

Data were analyzed in terms of two age classes of seedlings.

Seedlings 2 Years and Older.—Only one consistent treatment-stocking pattern was discernible. In absolute terms, milacre stocking was highest on the partial cut with no site preparation (PCO) treatment on all forests 5 and 10 years after harvest (table 1). The relatively high stocking levels on the PCO treatment were unexpected. Intermittent shade and mitigation of temperature and moisture extremes provided by the partial overstory may have offset the widely reported superiority of scarified seedbeds over duff for seedling establishment. Statistical evaluation showed milacre stocking was highly variable between treatments on all forests. Comparisons of stocking between treatments are shown in table 1.

Seedlings 5 Years and Older.—A more realistic assessment of stocking, based on seedlings 5 years and older, showed few significant differences ($\alpha = 0.05$) between treatments 10 years after harvest. Stocking of 5-year

Table 1.—Milacre plot stocking of 2-year and older seedlings 5 and 10 years after harvest, and 5-year and older seedlings 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests

		Years since harvest		
		5	10	10
National Forest	Harvest cutting-site preparation treatment	2-year and older seedlings	2-year and older seedlings	5-year and older seedlings
		Percent milacre stocking[1]		
Payette	CCS: Clearcut-scarify	42 ab	52 kl	21 tu
	CCB: Clearcut-broadcast burn	25 b	50 l	12 tu
	CCO: Clearcut-no site preparation	38 ab	52 l	14 u
	PCS: Partial cut-scarify	46 ab	77 jk	30 t
	PCO: Partial cut-no site preparation	50 a	84 j	16 tu
Teton	CCS: Clearcut-scarify	18 cd	67 mn	5 vw
	CCB: Clearcut-broadcast burn	20 cd	72 mn	5 vw
	CCO: Clearcut-no site preparation	12 d	52 n	10 v
	PCS: Partial cut-scarify	20 cd	52 n	0 w
	PCO: Partial cut-no site preparation	32 c	78 m	18 v
Uinta	CCS: Clearcut-scarify	18 ef	35 pq	0 x
	CCB: Clearcut-broadcast burn	12 ef	49 op	8 x
	CCO: Clearcut-no site preparation	8 f	23 q	3 x
	PCS: Partial cut-scarify	10 ef	34 pq	0 x
	PCO: Partial cut-no site preparation	25 e	58 o	5 x
Dixie	CCS: Clearcut-scarify	8 hi	10 rs	5 y
	CCB: Clearcut-broadcast burn	2 i	3 s	3 y
	CCO: Clearcut-no site preparation	15 h	18 r	10 y
	PCS: Partial cut-scarify	15 h	9 rs	6 y
	PCO: Partial cut-no site preparation	35 g	23 r	15 y

[1] Treatment stocking values within a forest, sharing a common letter within a column, are not significantly different ($\alpha = 0.05$).

and older seedlings was usually much lower than, but proportional to, 10-year postharvest stocking of 2-year and older seedlings by treatment and forest (table 1).

Density—Between Treatments

Data were analyzed in terms of two age classes of seedlings.

Seedlings 2 Years and Older.—The number of 2-year and older seedlings varied widely between some treatments on every forest, yet few of these differences were significant at the $\alpha = 0.05$ level (table 2). Lack of significance between treatments where density differences appear large was due to extreme variability between samples.

The treatment supporting the highest absolute density of seedlings 2 years and older changed from year 5 to year 10 on each forest, and was different for all forests 10 years after harvest. Lack of density trends either by year or forest indicates the volatility in natural regeneration when measured in terms of seedlings less than 5 years old. Treatments with the highest density 5 and 10 years after harvest were:

	5 years	10 years
Payette National Forest	CCS	PCS
Teton National Forest	PCO	CCB
Uinta National Forest	CCS	PCO
Dixie National Forest	PCO	CCO

Seedlings 5 Years and Older.—Evaluation of the number of established seedlings, 5 years and older, provides a less optimistic view of regeneration density. Only 17, 24, 13, and 46 percent, respectively, of the 2-year and older seedlings present at year 5 on the Payette, Teton, Uinta, and Dixie National Forests survived to year 10. Even though the number of established seedlings was low, density levels varied widely between some treatments on every forest (table 2). However, in only one case were density levels significantly different ($\alpha = 0.05$) between treatments (PCO and PCS treatments on the Teton National Forest). The general lack of significance

Table 2.—Seedling density of 2-year and older seedlings 5 and 10 years after harvest, and 5-year and older seedlings 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests

		Years since harvest		
		5	10	10
National Forest	Harvest cutting-site preparation treatment	2-year and older seedlings	2-year and older seedlings	5-year and older seedlings
		Seedlings per acre[1]		
Payette	CCS: Clearcut-scarify	5,848 a	7,581 g	742 n
	CCB: Clearcut-broadcast burn	1,678 a	3,062 g	188 n
	CCO: Clearcut-no site preparation	3,676 a	6,355 g	258 n
	PCS: Partial cut-scarify	2,371 a	7,486 g	800 n
	PCO: Partial cut-no site preparation	2,425 a	5,757 g	594 n
Teton	CCS: Clearcut-scarify	225 b	10,077 h	154 op
	CCB: Clearcut-broadcast burn	250 b	14,025 h	50 op
	CCO: Clearcut-no site preparation	250 b	4,575 h	175 op
	PCS: Partial cut-scarify	375 b	7,750 h	0 p
	PCO: Partial cut-no site preparation	525 b	9,725 h	175 o
Uinta	CCS: Clearcut-scarify	425 cd	486 jk	0 q
	CCB: Clearcut-broadcast burn	150 cd	1,595 i	81 q
	CCO: Clearcut-no site preparation	100 d	333 k	26 q
	PCS: Partial cut-scarify	375 cd	921 ij	0 q
	PCO: Partial cut-no site preparation	375 c	1,737 i	79 q
Dixie	CCS: Clearcut-scarify	175 ef	250 lm	50 r
	CCB: Clearcut-broadcast burn	25 f	29 m	29 r
	CCO: Clearcut-no site preparation	525 e	550 l	62 r
	PCS: Partial cut-scarify	231 ef	121 lm	75 r
	PCO: Partial cut-no site preparation	900 e	513 l	342 r

[1] Treatment seedling density values within a forest sharing a common letter within a column are not significantly different ($\alpha = 0.05$).

($\alpha = 0.05$) in density levels between treatments was due to wide variability in seedling numbers between samples.

In absolute terms, treatments with the highest densities of 5-year and older seedlings were:

Payette National Forest	PCS
Teton National Forest	PCO, CCO
Uinta National Forest	CCB
Dixie National Forest	PCO

Stocking—Within Treatments

Stocking showed a definite upward trend with increasing time since harvest on all forests except the Dixie. Because no seedlings were yet 5 years old at the 5-year postharvest measurement, within-treatment stocking comparisons from the fifth to the 10th year after harvest were made for 2-year and older seedlings only. Milacre stocking increased in absolute terms from the fifth to the 10th year for all treatments on the Payette, Teton, and Uinta National Forests (fig. 3). Stocking increases were significant on the partial cut treatments on the Payette, all treatments on the Teton, and the CCB and partial cut treatments on the Uinta National Forest.

The stocking trend on the Dixie differed noticeably from the other three forests. Milacre stocking remained stable or declined from year 5 to year 10 on all treatments, though none of the changes were significant at the $\alpha = 0.05$ level. Low initial stocking at year 5, with only minor within-treatment stocking changes by year 10, attests to the severe, high elevation regeneration environment on this forest.

Density—Within Treatments

Seedling density increased substantially with increasing time since harvest on all study areas except the Dixie. Because no seedlings were yet 5 years old at the 5-year postharvest measurement, within-treatment comparisons of density from the fifth to the 10th year were confined to 2-year and older seedlings. Density increased in absolute terms from year 5 to year 10 for all treatments on the Payette, Teton, and Uinta National Forests (fig. 4). These increases were significant ($\alpha = 0.05$) on the partial cut treatments on the Payette, all treatments on the Teton, and the CCB and PCO treatments on the Uinta National Forest.

In contrast, density by treatment changed little or declined relative to time since harvest on the Dixie National Forest. Seedling density from the fifth to the 10th year after harvest increased slightly on the clearcut treatments and declined moderately on the partial cut treatments on this forest, though none of the changes were significant ($\alpha = 0.05$). Lack of significant increases in density at year 10 from initially low levels at year 5 reflects the inherent difficulty of establishing natural regeneration above 10,000 ft on the Dixie.

Stocking-Density Relationships

Seedling density was significantly correlated ($\alpha = 0.05$) to milacre stocking on all forests 10 years after

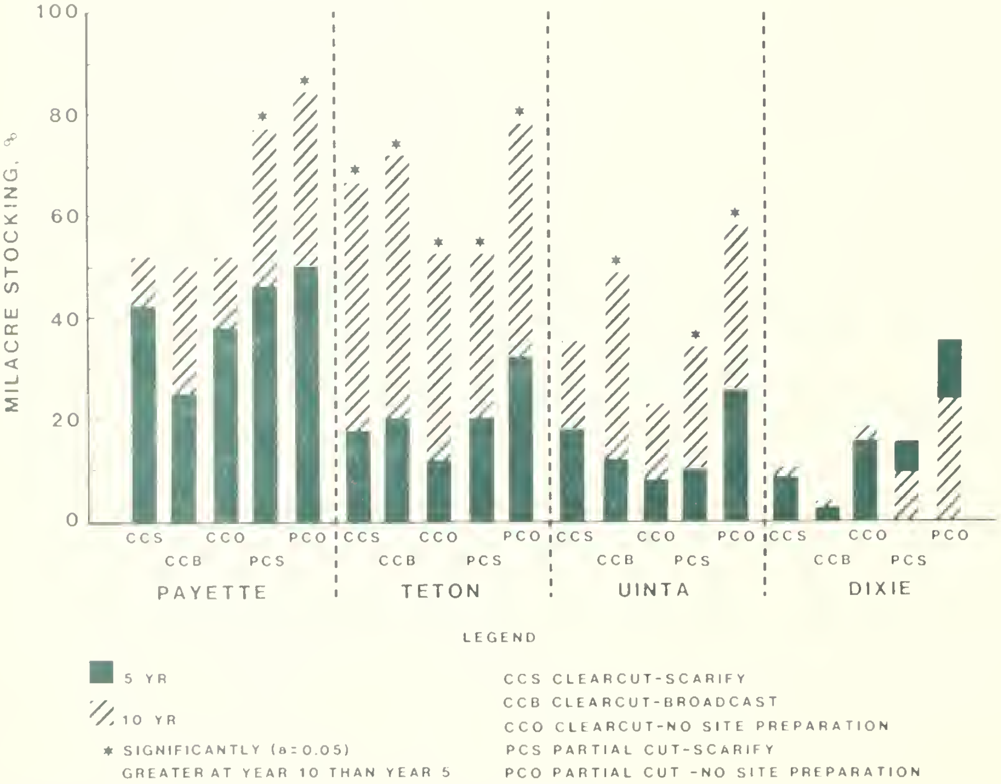

Figure 3.—A comparison of milacre stocking of 2-year and older seedlings 5 and 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests.

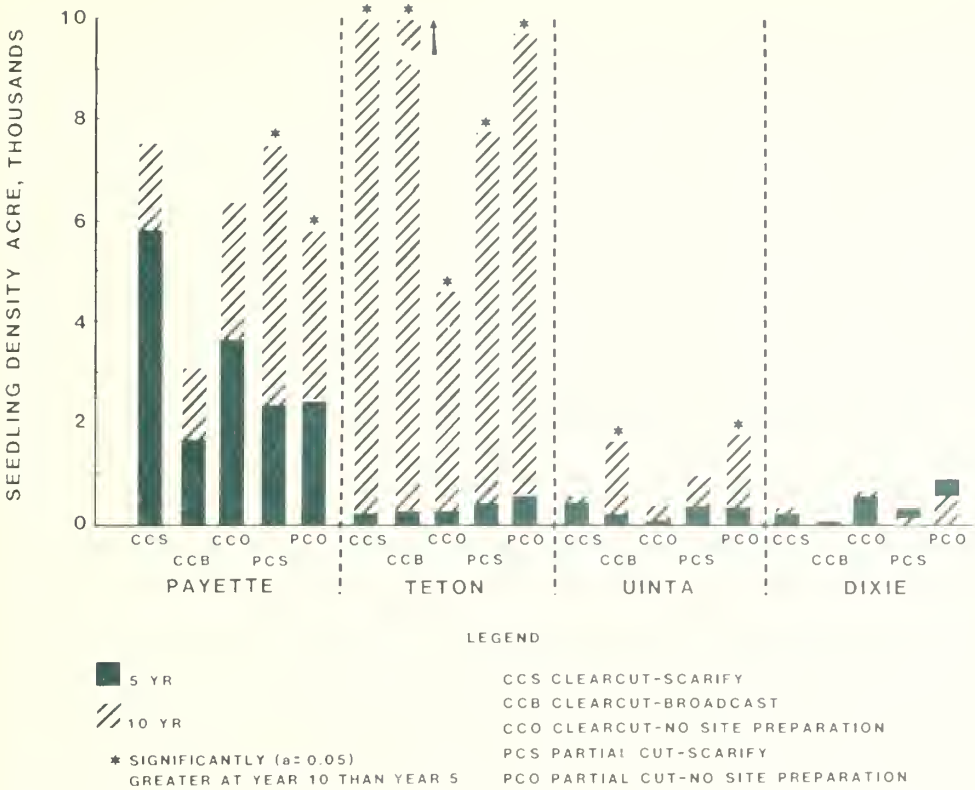

Figure 4.—A comparison of seedling density per acre of 2-year and older seedlings 5 and 10 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests.

harvest. A quadratic function best fit the combined stocking-density data for established (5-year and older) seedlings on all forests 10 years after harvest (fig. 5). Density varied directly with stocking, but at an increasing rate at higher stocking levels. Similar relationships between density and stocking have been reported by Harris (1967) and Seidel (1979).

Seedling Survival

The ratio of 5-year and older seedlings at year 10 to the total number of seedlings (age 1 to 4 years) present 5 years after harvest varied considerably between forests but averaged 10 percent for the four forests combined. While this study was not designed to assess causes of seedling mortality, low overall survival quantifies the extreme attrition rate of young seedlings in spruce-fir forests.

The survival rate of seedlings present 5 years after harvest to year 10 was 2 percent on the Teton, 7 percent on the Uinta, 18 percent on the Payette, and 41 percent on the Dixie National Forest. The survival rate was lowest on the Teton, the area with the highest seedling density at year 5, and highest on the Dixie, the area with the lowest initial density. This apparent disparity indicates that the few seedlings present 5 years after harvest in the harsh environment above 10,000 ft on the Dixie were on microsites that favored survival, and thus, nearly half (41 percent) lived to year 10. In contrast, the moist-to-wet conditions prevalent over much of the Teton study area provided a favorable medium for seedling germination. However, inundation and trampling destroyed a high proportion of these seedlings. A high water table resulting from overstory removal on the wet *Abies lasiocarpa/Streptopus amplexifolius* h.t. (ABLA/STAM) (Steele and others 1983) and heavy moose (*Alces alces*) activity associated with the moist *Abies lasiocarpa/Actaea rubra* h.t. (ABLA/ACRU) were major causes of mortality on the Teton.

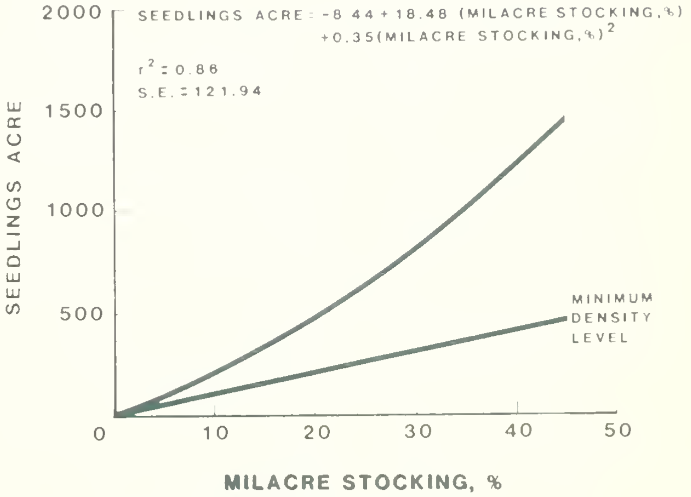

Figure 5.—Relationship of milacre stocking percent to seedling density per acre for 5-year and older seedlings on the Payette, Teton, Uinta, and Dixie National Forests. The minimum density line represents the stocking-density relationship if there was only one seedling on each stocked milacre plot.

Because site preparation within treatments was never totally accomplished, regeneration data for each of the five treatments were compared between 20 randomly located plots representing the average of the site treatment and 20 subjectively located plots representing the actual (assigned) treatment. For example, random plot locations on broadcast burn treatments usually fell on burned seedbed but occasionally on unburned duff or mineral soil, while subjectively located plots were always installed on burned seedbed.

Milacre stocking of 5-year and older (established) seedlings did not vary significantly ($\alpha = 0.05$) between the average of the site treatment and actual seedbed surface for any treatment on any forest (table 3). Density of established seedlings also did not vary significantly between actual and average seedbed conditions for any treatment/forest combination (table 4).

Distinct differences have been reported in regeneration of spruce and fir on different seedbeds (Muri 1955; Smith 1955; Roe and Schmidt 1964). Engelmann spruce germinates best on mineral soil seedbeds (U.S. Department of Agriculture 1948; Fiedler 1976). Barr (1930) noted that mineral soil generally loses moisture less rapidly than duff with seasonal drying, resulting in higher spruce germination and lower drought losses. Furthermore, Daniel and Glatzel (1966) found duff seedbeds could be lethal to overwintering Engelmann spruce seeds. Subalpine fir also regenerates well on mineral seedbeds, but because fir has greater first-year root elongation than spruce, it is better equipped to survive on duff surfaces (Smith 1955; Day 1964; Eis 1965).

We also examined regeneration by species in relation to actual seedbed surface to determine if the species-seedbed relationships reported above hold for these Intermountain sites. To do this, we pooled regeneration data from each forest on the basis of actual seedbed surface—that is, mineral, burned, or duff—regardless of treatment. We then calculated stocking and density for Engelmann spruce and subalpine fir on mineral, burned, and duff seedbeds.

Regeneration by species varied not only by seedbed but also by location and elevation. Relative stocking success of both Engelmann spruce and subalpine fir varied inversely with elevation on mineral seedbeds and directly with elevation on duff seedbeds. Stocking levels

Table 3.—Milacre plot stocking of 5-year and older seedlings on randomly located plots representing the average site treatment and on subjectively located plots representing the actual prescribed treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Cutting method	Scarification		Broadcast burn		No site preparation	
		Average	Actual	Average	Actual	Average	Actual
		Percent					
Payette	Clearcut	17	31	0	25	5	17
	Partial cut	22	35	—	—	10	22
Teton	Clearcut	5	5	0	10	5	15
	Partial cut	0	0	—	—	20	15
Uinta	Clearcut	0	0	5	11	0	5
	Partial cut	0	0	—	—	5	5
Dixie	Clearcut	5	5	6	0	15	5
	Partial cut	12	0	—	—	10	20

Table 4.—Seedling density of 5-year and older seedlings on randomly located plots representing the average site treatment and on subjectively located plots representing the actual prescribed treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Cutting method	Scarification		Broadcast burn		No site preparation	
		Average	Actual	Average	Actual	Average	Actual
		Seedlings per acre					
Payette	Clearcut	611	923	0	375	105	500
	Partial cut	277	1,353	—	—	158	1,056
Teton	Clearcut	250	53	0	100	50	300
	Partial cut	0	0	—	—	200	150
Uinta	Clearcut	0	0	53	111	0	53
	Partial cut	0	0	—	—	53	105
Dixie	Clearcut	50	50	59	0	400	300
	Partial cut	118	0	—	—	105	550

of both spruce and fir were sharply higher on mineral than on duff seedbeds on the 6,000-ft Payette site, somewhat higher on the 8,600-ft Teton site, slightly lower on the 9,500-ft Uinta site, and similar for spruce and much lower for fir on the 10,300-ft Dixie site (table 5). This elevational gradient is directly correlated with the geographic north-south locations of the four study sites. The gradual shift in relative stocking success from mineral to duff seedbeds with increasing elevation is logical when examined in light of changes in seedling environment that accompany changes in elevation.

While both spruce and fir germinate well on mineral seedbeds, duff possesses several advantages over mineral seedbeds for seedling survival at higher elevations. Duff lessens the impact of frequent, high-intensity summer storms that can wash out or bury young seedlings. Rainstorms with intensities of up to 8 inches per hour have been reported in Utah's mountains—severe enough to cause surface erosion problems (Croft and Marston 1950). Duff also provides protection from frost heaving, a common phenomenon on high elevation mineral seedbeds before snow cover in the fall and after snowmelt in the spring. Noble and Alexander (1977) reported that frost heaving accounted for 3 to 27 percent of total seedling mortality on mineral seedbeds but caused no mortality on duff seedbeds above 10,000 ft in Colorado's spruce-fir zone.

Seedling density/seedbed relationships by species followed a pattern similar to stocking. Densities of both Engelmann spruce and subalpine fir were higher on mineral than on duff seedbeds at lower elevations, with a transition to higher relative densities on duff seedbeds at high elevations (table 6).

The regeneration advantage reported for subalpine fir over Engelmann spruce on duff seedbeds was not evident in this study. Studies in the Canadian, northern, and central Rockies have reported drought as a major cause of spruce seedling mortality on duff seedbeds. Drought was also reported as a major cause of spruce mortality in another regeneration study on the Dixie National Forest (Hanley and Pfister 1983). However, Roe and Schmidt (1964) reported that moisture generally did not appear critical to seedling survival in the Intermountain spruce-fir zone.

Burned seedbed conditions apparently ameliorated over time on the less severe sites and became increasingly favorable for seedling establishment. In absolute terms, stocking and density of both Engelmann spruce and subalpine fir were lowest on burned seedbeds on all forests 5 years after treatment (tables 5 and 6). However, spruce stocking and density increased dramatically on burned seedbeds by year 10 on the Payette, Teton, and Uinta, and fir increased on the Payette and Teton National Forests. Fiedler (1980) found similar sharp increases in regeneration with increasing time since treatment on burned seedbeds in the spruce-fir zone of Montana.

Table 5.—Milacre plot stocking of 2-year and older seedlings by species, seedbed, and time since treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Species	Time since treatment	Mineral seedbed	Burn seedbed	Duff seedbed
		Years	*Percent*		
Payette	Engelmann spruce	5	47	7	13
		10	64	36	40
	Subalpine fir	5	46	0	21
		10	68	18	33
	All	5	56	7	23
		10	76	41	50
Teton	Engelmann spruce	5	12	4	10
		10	60	80	44
	Subalpine fir	5	10	4	9
		10	19	36	14
	All	5	20	4	18
		10	63	92	44
Uinta	Engelmann spruce	5	14	8	14
		10	33	59	37
	Subalpine fir	5	5	0	7
		10	3	0	4
	All	5	14	8	18
		10	34	59	37
Dixie	Engelmann spruce	5	6	0	10
		10	6	0	5
	Subalpine fir	5	4	0	15
		10	2	0	15
	All	5	10	0	21
		10	6	0	18

Table 6.—Seedling density of 2-year and older seedlings by species, seedbed, and time since treatment on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Species	Time since treatment	Mineral seedbed	Burn seedbed	Duff seedbed
		Years	*Seedlings per acre*		
Payette	Engelmann spruce	5	3,218	74	645
		10	5,842	1,454	1,404
	Subalpine fir	5	1,942	0	500
		10	3,842	227	788
	All	5	5,160	74	1,145
		10	9,684	1,682	2,192
Teton	Engelmann spruce	5	178	120	158
		10	8,060	25,280	2,965
	Subalpine fir	5	144	40	105
		10	402	560	210
	All	5	322	160	263
		10	8,462	25,840	3,175
Uinta	Engelmann spruce	5	231	100	339
		10	700	2,054	750
	Subalpine fir	5	48	0	89
		10	40	0	38
	All	5	279	100	428
		10	740	2,054	788
Dixie	Engelmann spruce	5	154	0	127
		10	174	0	61
	Subalpine fir	5	58	0	407
		10	43	0	351
	All	5	212	0	534
		10	217	0	412

Ten years after treatment, subalpine fir was absent on burned seedbeds on the Uinta National Forest, and both spruce and fir were absent on burned surfaces on the Dixie. Establishment difficulties on burned seedbeds were apparently greater and more persistent on these high elevation Utah sites.

Engelmann spruce stocking and density increased sharply on all seedbeds from the fifth to the 10th year after treatment on the Payette, Teton, and Uinta National Forests. Fir stocking and density also increased on all seedbeds on the Payette and Teton, though increases were less than for spruce.

SUMMARY

Results of this study are generally consistent with findings of other studies of regeneration in the subalpine zone. We found, along with Noble and Ronco (1978) in Colorado, Fiedler (1980) in Montana, and Minore and Dubrasich (1981) in Oregon, that natural regeneration is a slow process following harvest cutting in subalpine forests.

Although the number of germinates was high in this study, especially on the Payette and Teton, few seedlings survived the first growing season, and fewer yet reached age 5. If the age criterion of 5 years is used to define an established seedling (Noble and Ronco 1978), stocking and density levels were low on all treatments and forests 10 years after harvest. Overall, only 10 percent of the seedlings (age 1 to 4 years) present 5 years after harvest survived to year 10. This highlights the extreme attrition rate in these forests and the extended regeneration period needed to reach full stocking.

Examination of regeneration by species in relation to actual seedbed surface, regardless of treatment, revealed several relationships:

1. Regeneration of both Engelmann spruce and subalpine fir was higher on mineral than duff seedbeds at lower elevations, with a gradual transition to higher relative stocking levels on duff seedbeds at higher elevations. This shift was attributed to the seedling survival advantages of duff seedbeds at high elevations, namely, insulation from frost heaving and protection from surface erosion caused by high-intensity summer storms.

2. In contrast to other studies, we found subalpine fir had no distinct regeneration advantage over Engelmann spruce on duff seedbeds. Regeneration studies in other sections of the Rockies have reported spruce more drought susceptible than fir on duff seedbeds, though Roe and Schmidt (1964) found that moisture was generally not critical to seedling establishment in the geographical area covered by this study.

3. Regeneration in absolute terms was lowest on burned seedbeds at all locations 5 years after harvest but increased dramatically by year 10 on all forests

except the Dixie. Seedling establishment difficulties on burned seedbeds were greater and longer lasting on the high elevation Utah forests. Ten years after harvest, fir was still missing from burned seedbeds on the Uinta, and both Engelmann spruce and subalpine fir were absent on burned seedbeds on the Dixie.

We were unable through this study to identify a preferred harvest cutting-site preparation prescription for securing regeneration on any forest. However, we did find that the pattern of regeneration was not the same at all locations. On the Payette, Teton, and Uinta, stocking and density of 2-year and older seedlings increased substantially in absolute terms from the fifth to the 10th year after harvest, in spite of high seedling mortality rates (that is, less than 10 percent of the seedlings present at year 5 on these forests survived to year 10). In contrast, initially low stocking and density levels on the Dixie changed little from the fifth to the 10th year after harvest. Yet nearly half of the small number of seedlings present at the 5-year measurement on this forest survived to year 10.

Germination and early survival were moderately to sharply higher and percent survival to year 10 somewhat lower on the three northern forests than on the Dixie. Though germination and early seedling survival patterns varied between the four forests, regeneration status in terms of established (5-year and older) seedlings did not differ greatly at year 10. Because of the high mortality rate of young seedlings on all forests, we believe distribution and number of 5-year and older seedlings, rather than 2- to 4-year-old seedlings, provide a more realistic basis for describing and comparing the regeneration status of these sites. On this basis, stocking and density levels were highest on the Payette, intermediate on the Teton and Dixie, and lowest on the Uinta.

While the overall regeneration picture is gradually improving, stocking and density of established seedlings were still at low levels on all study areas 10 years after harvest. If extended regeneration periods are not compatible with management objectives, planting will be necessary to augment the gradual natural restocking that typifies these high elevation Intermountain forests.

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This paper describes the natural regeneration process for 10 years following five harvest cutting-site preparation treatments in spruce-fir forests of Idaho, Utah, and Wyoming. High seedling mortality throughout the period resulted in slow accumulation of established seedlings on all treatments.

KEYWORDS: *Picea engelmannii*, *Abies lasiocarpa*, natural regeneration, harvest cutting, site preparation

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United States
Department of
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**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-344

June 1985

Woodland Tree Volume Estimation: A Visual Segmentation Technique

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ACKNOWLEDGMENTS

Data for this study were collected in cooperation with the U.S. Department of the Interior, Bureau of Land Management in Nevada and Utah. Special thanks to Dave Schmidt, Steve Langdon, and Jason Teegaurden, former temporary employees of the Intermountain Research Station, who collected most of the field data. The Bureau of Land Management at Ely, NV, provided the inventory data for use in table 3.

RESEARCH SUMMARY

Visual segmentation, a technique for estimating cubic foot volume of woodland tree species, was compared with actual volume measurement. Comparison was made during a forest inventory of pinyon-juniper woodlands in Nevada and Utah. The visual technique's accuracy, its usefulness in developing volume equations, and applicability to volume inventory were studied. This study indicated visual segmentation is not reliable for estimating volume for a single tree. However, a sample of visually estimated volumes proved adequate for developing volume equations. In an application, a bias of 0 to −9 percent of the mean cubic foot volume per acre resulted from summary of 176 plots, using volume equations developed with visually estimated data. An appendix includes a complete description of the visual volume estimation technique for field use.

Woodland Tree Volume Estimation: A Visual Segmentation Technique

J. David Born
David C. Chojnacky

INTRODUCTION

In the arid Rocky Mountain regions, vast acreages of trees once ignored by foresters are now drawing attention as a source of wood fiber. Of interest are the various species of pinyon, juniper, mountain-mahogany, mesquite, and the evergreen and deciduous oaks. Lowe (1972) grouped these trees in an ecological community known as woodland. In order to assess the wood fiber resource of woodland trees, simple cost-effective volume measurement methods are needed.

Estimating tree volume is a standard concept for foresters, but the shrublike multiple-stem character of woodland species creates new problems that were not considered in the development of volume mensuration methods. Traditional volume measurements, designed for commercial timber species, have focused on the main bole. But a large percentage of the wood in a woodland tree is found in the branches, and frequently a main bole is not well defined.

A cubic measure of wood for all stems and branches is a reasonable approach to assessment of woodland species. In this approach, all linear segments of stem and branch wood are identified, and then volume is calculated for each segment with the appropriate geometric solid formula. Summing the segment volumes produces a volume per tree. However, measuring the necessary diameters and length of each segment is a costly, time-consuming task. For example, a single large juniper tree can have more than 100 1- to 6-foot wood segments.

Rather than measure each tree, sample trees are usually measured for use in constructing volume equations. This then leads to the question of how sample tree volume data can be obtained in an efficient and timely manner for the vast areas of woodlands in the Rocky Mountain States.

BACKGROUND

In previous woodland tree studies, some researchers have estimated wood volume indirectly by first weighing a tree and then converting the weight to volume through specific gravity factors (Felker and others 1983; Weaver and Lund 1982; Miller and others 1981; Storey 1969). Others have cut trees into segments to measure segment diameters and length needed to calculate volume (Howell 1940; Gholz 1980). Weighing trees and cutting trees into sections are suitable techniques for research work where motorized equipment access is good and where the land owner will allow trees to be destroyed for use in a study.

Clendenen (1979) developed volume equations using volume data collected using a method adapted from Cost's (1978) work for measuring volume of standing trees without cutting them down. This method, known as "visual segmentation," does not require a physical measurement of each stem segment (Born and Clendenen 1975). Instead, each segment in a tree is classified into a 2-inch midpoint diameter (outside bark) by 2-foot midpoint length class (since this study, the procedure has been changed to 1-foot length classes). The appendix has a full description of the procedure.

After classification, volumes are computed from the segment diameter class and length class values instead of exact dimensions. Each segment is assumed to be a paraboloid frustum, and Huber's formula (Husch and others 1982, p. 101) is used to compute the volume of each segment:

$$V_i = 0.005454\ H_i D_i^2$$

where

V_i = volume of the ith segment (cubic feet)
H_i = length class of the ith segment (feet)
D_i = diameter class of the ith segment (inches).

Success of visual segmentation is dependent upon (1) correct classification of the segments and (2) the length and diameter class values underestimating and overestimating the actual dimensions in an equal proportion. The following algebraic manipulation of Huber's formula (using class dimensions) illustrates the second point:

$$V = \sum_{i=1}^{n} 0.005454\ (H_i+h_i)(D_i+d_i)^2 \qquad (1)$$

$$= \sum_{i=1}^{n} \{0.005454\ H_i D_i^2\}$$
$$+ \sum_{i=1}^{n} \{d_i[0.005454\ (2D_iH_i+d_iH_i)]$$
$$+ h_i[0.005454\ (D_i+d_i)^2]\} \qquad (2)$$

where

V = volume of a tree (cubic feet)
H_i+h_i = actual length of the ith segment (feet)
D_i+d_i = actual diameter of the ith segment (inches)
h_i = ±deviation (up to 1 foot) of actual segment length from H_i
d_i = ±deviation (up to 1 inch) of actual segment diameter from D_i.

The second summation (Σ) in equation (2) must sum to zero, if the volume of a tree is properly represented by using class values instead of actual dimensions in Huber's formula. This will happen only if the d_i's and h_i's sum to zero for fixed D_i and H_i. This will occur with greater probability for large n; that is, for trees with many segments or for estimating volume for a group of trees.

The study in this paper compares volume estimates from visual segmentation with volume estimates obtained from exact measurements of segments from trees destructively sampled.

FIELD DATA COLLECTION

In 1980, volume samples were collected for 248 pinyon and juniper trees on lands in Nevada managed by the U.S. Department of the Interior, Bureau of Land Management (BLM). An additional 55 trees were sampled in 1981 on BLM lands in Nevada and Utah. From two to six trees were selected at each of the 61 locations. The locations were a small subsample of the BLM woodland inventory. The sampling was done as a secondary task of a U.S. Department of Agriculture, Forest Service, Forest Survey quality control crew. Because of this, no attempt was made to design the subsample, other than to distribute it throughout the inventory area.

In 1980, trees within the locations were selected in proportion to crown area using transects (Meeuwig and Budy 1981). Because the first year's sample was weak in the larger diameter classes, those taken during the 1981 field season were purposely selected in larger diameter classes. Individual tree measurements included diameter at root collar (DRC), number of stems, crown widths, total height, and location description data (USDA Forest Service 1982). Volume measurements of each tree were obtained by (1) visual segmentation and (2) destructive segmentation.

For visual segmentation, numbers of stem segments were counted in classes of 2-inch midpoint diameter by 2-foot length. The estimator proceeded in a systematic fashion from the base of a tree upward, recording each segment in the appropriate class (see appendix). Two or three visual volume estimates were done for each tree, two by a U.S. Forest Service (FS) quality control crew and usually one by a BLM crew. In 1981, when the last 55 trees were sampled, only the FS crew members made visual volume estimates.

Destructive segmentation involved cutting down trees in order to measure diameter and length dimensions for each segment. Segment lengths were chosen to roughly parallel the visual method, although an exact rule was not established. Tapers of segments were to be less than 15 to 20 percent. Segment length, diameter (outside bark) at both ends, and diameter at the midpoint were recorded for each segment. The destructive segmentation provided data to compute accurate volume estimates for comparison with the visual segmentation estimates.

DATA ANALYSIS AND RESULTS

We investigated three aspects of visual segmentation: (1) its accuracy for estimating volume of individual trees, (2) its usefulness for volume equation development, and (3) the consequences of applying volume equations based on visual segmentation data.

Testing for Accuracy

Before testing, the data were grouped by species, tree size, and estimator group (field crews). Two species—singleleaf pinyon (*Pinus monophylla* Torr. & Frem.) and juniper (*Juniperus osteosperma* [Torr.] Little)—were represented. Four-inch diameter classes were selected to minimize effect of tree size on the comparisons, as trees ranged from 3 to over 20 inches DRC. There were up to three visual volume estimates and a destructive volume estimate for each tree. The crews doing the visual estimating were placed into three groups and called FS1, FS2, and BLM. FS1 was the same estimator for all samples. FS2 included two estimators, one of whom did only 55 of 303 trees. The BLM group included as many as 15 estimators. All estimators attended the same training sessions.

Test statistic.—The statistic used to make the comparisons within groups was the average difference *(diff)* between visual and destructive volume estimates:

$$diff = \sum_{i=1}^{n} \frac{(v_i - d_i)}{n}$$

where

diff = average difference between visual and destructive estimates

v_i = visual volume estimate of the ith tree

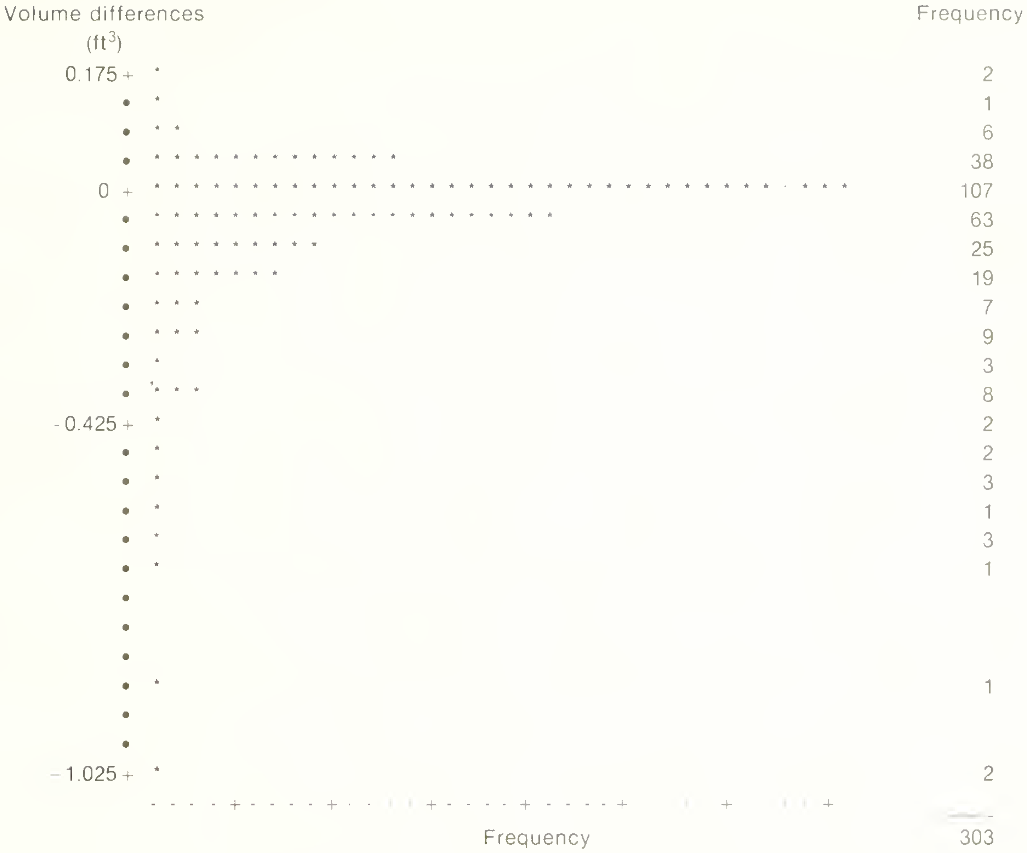
d_i = destructive volume estimate of the ith tree

n = sample size for a group.

The visual (v_i) and destructive (d_i) volume estimates were computed by Huber's and Newton's cubic-foot log formulas, respectively (Husch and others 1982, p. 101). Different formulas were used because slightly different measurement procedures were used for visual and destructive volume estimates. Husch points out that Newton's formula is the most flexible and best formula available for logs measured at three diameter points. Because the destructive samples had three diameter measurements, Newton's formula was selected. On the other hand, the visual estimates had only one diameter measurement and were limited to Huber's formula. The difference between the formulas was fairly negligible, as shown by figure 1. The difference, however, is given in table 1 for later use in interpretation of results in table 2.

Background on tests.—Testing for accuracy of a statistic or estimator actually involves testing two components—bias and precision. Bias is the expected difference between any statistic and its true value. In our case, *diff* is the statistic of interest and its true value is zero. A biased statistic from a sample survey cannot be improved by increasing sample size. Precision describes how widely a statistic can fluctuate around its true value. The variance of *diff* is a measure of precision for our statistic. An imprecise statistic can usually be improved by increasing sample size.

Student's t-test can be used to compare visual volume estimates with destructive estimates from the same trees to determine bias, although it is a poor test for



Each * may represent up to three trees

Figure 1.—Frequency distribution (stem-and-leaf plot) between Huber's volume formula and Newton's volume formula applied to the destructive sample data. Volumes for each tree were computed by the two formulas and the difference of Huber's minus Newton's is plotted.

Table 1.—Comparison between wood and bark volume computed by Huber's formula minus volume computed by Newton's formula for destructive sampled trees

Diameter class	Species	Number of trees	Mean volume difference		Median volume difference
DRC inches			*Ft³*	*Percent*[1]	*Ft³*
3 – 6.9	Juniper	23	0.05	−10	−0.01
	Pinyon	53	−.07	−11	−.05
	Pinyon and juniper	76	−.07	−12	.04
7 – 10.9	Juniper	51	−.08	−4	−.03
	Pinyon	60	−.12	−3	−.05
	Pinyon and juniper	111	−.10	−3	−.04
11 – 14.9	Juniper	35	−.07	1	−.03
	Pinyon	32	−.15	1	−.09
	Pinyon and juniper	67	−.11	−1	−.06
15 – 18.9	Juniper	19	.03	0	−.01
	Pinyon	16	−.15	0	−.06
	Pinyon and juniper	35	−.08	−1	−.04
>19	Juniper	11	−.05	0	−.01
	Pinyon	3	−.10	0	−.03
	Pinyon and juniper	14	−.06	0	−.01
Total	Juniper	139	−.06	−1	−.02
	Pinyon	164	−.11	−2	−.05
	Pinyon and juniper	303	−.09	−2	−.04

[1] Mean percent difference is the mean volume difference divided by the mean volume computed by Newton's formula.

Table 2.—Comparison between visual segmentation and destructive segmentation using the difference statistic *(diff)*. The confidence intervals (CI's) contain the mean difference (DIFF) unless a 1-in-20 chance in sampling has occurred

Diameter class	Estimator	Number of trees	Mean Volume difference		Volume difference			t-test		Chi-squared	
					Mean	Medium	Minimum	Lower CI	Upper CI	Lower CI	Upper CI
Inches			*Ft³*	Percent[1]	*Ft³*						
					Juniper						
3–6.9	BLM	8	0.04	6	0.03	0.51	-0.78	-0.34	0.27	-0.09	0.13
3–6.9	FS1	23	0	0	-.05	.94	-1.22	-.17	.16	-.03	.04#
3–6.9	FS2	23	-.06	-14	-.06	.25	-.74	-.15	.02	-.08	-.04*
7–10.9	BLM	18	-.09	-4	.18	1.58	-4.48	-.76	.59	-.19	.13
7–10.9	FS1	51	.17	9	-.05	1.58	-4.92	-.42	.09	-.19	-.12*#
7–10.9	FS2	51	-.16	-9	-.07	1.08	-4.96	-.39	.08	-.18	.12*#
11–14.9	BLM	18	-.09	-2	-.44	4.16	-2.99	-.87	.69	-.22	.15
11–14.9	FS1	35	-.73	-13	-.67	3.49	-3.09	-1.24	-.21*#	-.80	-.61*#
11–14.9	FS2	35	-.40	-7	-.17	2.89	-4.63	-.89	.09	-.47	-.30*#
15–18.9	BLM	10	-.53	-7	-.49	.78	2.14	-1.27	.21	-.68	-.14*#
15–18.9	FS1	19	.78	9	-.05	21.03	-2.40	-1.64	3.20	.39	1.53*#
15–18.9	FS2	19	.88	11	.36	7.28	-1.90	-.26	2.02	.69	1.25*#
>19	BLM	7	-1.33	-7	.43	5.10	-8.78	-5.51	2.86	-2.14	1.21
>19	FS1	11	1.39	7	.73	14.48	-5.98	-3.32	6.10	.53	3.47*#
>19	FS2	11	-2.09	-11	-1.56	11.03	-9.88	-6.06	1.88	-2.85	-.27*#
Total	BLM	61	-.30	-5	-.02	5.10	-8.78	-.78	.19	-.35	-.22*#
Total	FS1	139	-.03	1	-.07	21.03	5.98	.50	.45	-.06	.02
Total	FS2	139	-.21	-5	-.09	11.03	-9.88	-.57	.14	-.24	-.18*#
					Pinyon						
3–6.9	BLM	27	.03	5	.05	.52	-.43	-.04	.11#	.02	.05*#
3–6.9	FS1	53	.06	10	.03	.64	-.49	0	.12#	.05	.07*#
3–6.9	FS2	53	-.04	-7	-.01	.43	-.97	.09	.01	-.05	-.03*#
7–10.9	BLM	33	-.24	-6	-.25	1.69	-2.62	-.62	.14	-.29	-.16*#
7–10.9	FS1	60	14	4	.11	4.82	2.27	-.16	.44	.11	.19*#
7–10.9	FS2	60	-.39	-10	-.13	1.10	3.86	-.65	-.13*#	-.42	-.35*#
11–14.9	BLM	20	-.62	-6	-.43	3.36	-5.16	-1.47	.24	-.76	-.35*#
11–14.9	FS1	31	-1 12	10	-1.12	4.63	-7.84	2.10	-.14*	-1.27	-.88*#
11–14.9	FS2	31	-1.41	-13	1.63	2.06	-5.67	-2.11	-.71*#	-1.53	-1.21*#
15–18.9	BLM	8	-2.96	13	-2.59	3.83	-13.69	8.20	2.27	-4.05	.15
15–18.9	FS1	16	-.26	-1	-.71	10.85	-10.01	-3.31	2.79	-.76	.78
15–18.9	FS2	16	-1.42	-5	-1.35	5.81	9.23	3.24	.40	-1.75	-.75*#
>19	BLM	1	7.68	13	7.68	7.68	7.68			.91	27.72*#
>19	FS1	3	-6.19	-12	-4.85	-4.80	-8.93	-12.09	-.30*#	-8.60	8.96
>19	FS2	3	1.89	-4	-2.08	.61	-4.20	-7.88	4.10	-2.90	4.48
Total	BLM	89	-.40	-6	-.03	7.68	-13.69	-.90	.11	-.44	-.34*#
Total	FS1	163	-.28	-4	-.03	10.85	-10.01	.65	.09	-.31	-.25*#
Total	FS2	163	-.60	-8	-.11	5.81	-9.23	-.84	-.35*#	-.62	-.58*#
					Pinyon and juniper						
Total	BLM	150	-.36	-6	-.03	7.68	-13.69	.71	-.01*	-.38	-.32*#
Total[2]	FS1	302	-.16	-3	-.05	21.03	-10.01	-.46	.13	-.18	-.15*#
Total[2]	FS2	302	.42	-7	-.11	11.03	9.88	.63	-.21*#	-.43	-.41*#

*Ninety-five percent confidence interval does not contain zero.

#Ninety-five percent confidence interval does not contain the negative value from table 1

[1] Mean percent difference is the mean volume difference divided by the mean volume computed by Newton's formula.

[2] This total for number of trees does not equal the totals in figure 1 and table 1 because of a data collection error in omitting visual segmentation of one tree.

precision. Freese (1960) suggests a chi-square test if both bias and precision are of concern.

All statistical analyses are done in terms of 95 percent confidence intervals instead of testing single point estimates. Confidence intervals give more information than simple tests that just accept or reject a hypothesis. Also, confidence intervals allow the reader to select either zero or a value from table 1 as the test criterion. A 95 percent confidence interval can be interpreted as an interval having a 19-in-20 chance for containing the true population value.

The t-test for paired differences is given in Steel and Torrie (1960) and can be expressed in terms of a 95 percent confidence interval:

$$\text{Prob}\left([\mathit{diff} - (t_{0.025:n-1}S_d)] \le \text{DIFF} \le [\mathit{diff} + (t_{0.025:n-1}S_d)]\right) = 95\%$$

where

t = the value obtained from a t-table at $\alpha = 0.025$ probability level for n−1 degrees of freedom

S_d = the standard error of the mean difference (*diff*)

n = the sample size of the groups of differences being tested

DIFF = the expected (true population) value of *diff* (it is either zero or the values in table 1).

Freese (1960) gave a computing formula for the chi-square test, but not in the form of a confidence interval.

The pivotal-quantity method (Mood and others 1974, p. 379) was used to derive the following 95 percent confidence interval:

$$\text{Prob}\left(\left[diff - \frac{1.96}{n}\sqrt{\frac{diffsq}{\chi^2_{0.025:n}}}\right] \le \text{DIFF} \le \left[diff + \frac{1.96}{n}\sqrt{\frac{diffsq}{\chi^2_{0.975:n}}}\right]\right) = 95\%$$

where

χ^2 = values obtained from a chi-square table at the 0.025 and 0.975 probability levels for n degrees of freedom

$$diffsq = \sum_{i=1}^{n} (v_i - d_i)^2.$$

Accuracy test results.—Results on the accuracy of visual segmentation are given in table 2 for each of the three estimators. The mean differences *(diff)* are mostly negative and range from −3 to −7 percent for the pinyon and juniper totaled over all diameter classes. Median, maximum, and minimum differences are also given. The median tends to be closer to zero than the mean. The maximum and minimum illustrate the extremes that can result from visual segmentation.

According to the t-test confidence intervals, the mean population difference (of visual minus destructive estimates) could be zero for most diameter class groups. The most noteworthy exceptions are for totals having mean differences larger than −6 percent. For individual diameter classes, −10 to −13 percent differences are required in order to have t-test significance.

The chi-square test, on the other hand, shows that the mean population differences would rarely include zero. This conservative test is more sensitive to the large variation found in each individual visual estimate.

These results indicate that visual segmentation tends to be unbiased (according to t-test) but is inaccurate (according to chi-square test) for estimating volume for a single tree. In the table 2 confidence interval tests, substituting mean percent differences given in table 1 for zero does not significantly alter results. However, our use of Newton's formula to compute volume in destructive segmentation probably contributes somewhat to the negative values consistently observed in table 2 for the mean difference between visual and destructive segmentation.

Volume Equations

The visual segmentation method was not intended to provide accurate volume predictions for single trees. We primarily devised it to provide large amounts of inexpensive data for volume equation development. Neter and Wasserman (1974) point out that measurement errors in a dependent variable used for regression modeling will present no problems if the errors are random. In our case, this means the visual estimates must vary in a random manner. This assumption can easily be examined by comparing regression volume equations developed from both the visual and destructive sample data.

A simple regression model using only DRC and height as predictor variables was selected for the comparison. Other variables were available, but they added little to the predictive power of DRC and height. Combining DRC and height into one variable, DRC squared times height (DRSQH) worked well. A natural log transformation of the data was made to minimize the increasing variance of the volume data with increasing tree size and to satisfy general linear model theory requirements for hypothesis testing. The log-transformed model may not be the best approach for developing pinyon-juniper volume equations, but it was adequate for our evaluation of visual segmentation.

In figures 2 and 3, regression equations in natural log units for all groups are compared against the 95 percent confidence bands for individual predictions from destructive sample data. It is hard to distinguish differences between the four regression lines, as all lie well within the 95 confidence bands. However, results expressed in the log-transformed units can be deceptive for making inference in cubic feet.

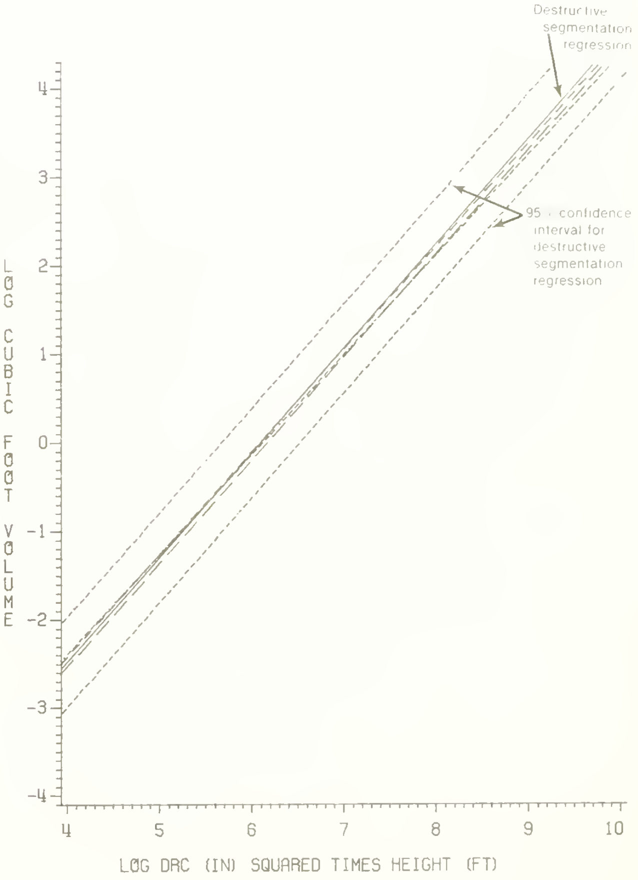


Figure 2.—Pinyon destructive segmentation data in log units with regression line (solid line) and 95 percent confidence bands (for individual predicted values) fit to data. Three dashed lines representing regression equations for visual estimates are overlaid.

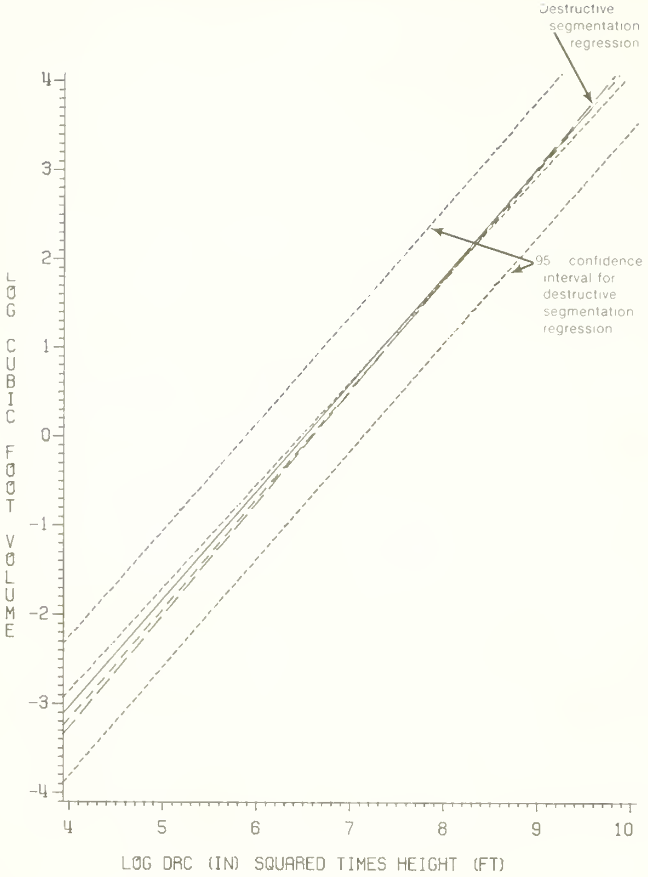


Figure 3.—Juniper destructive segmentation data in log units with regression line (solid line) and 95 percent confidence bands (for individual predicted values) fit to data. Three dashed lines representing regression equations for visual estimates are overlaid.

Figures 4 and 5 illustrate the equation predictions converted back to cubic feet. Now, a tendency toward a negative bias is evident for the pinyon equations. The graph of the juniper equations indicates less bias than observed for pinyon.

The volume equations based on the visual data are surprisingly close to the equation based on the destructive data. However, a small negative bias is evident in figures 2 to 5. This corresponds to the previous findings in table 2.

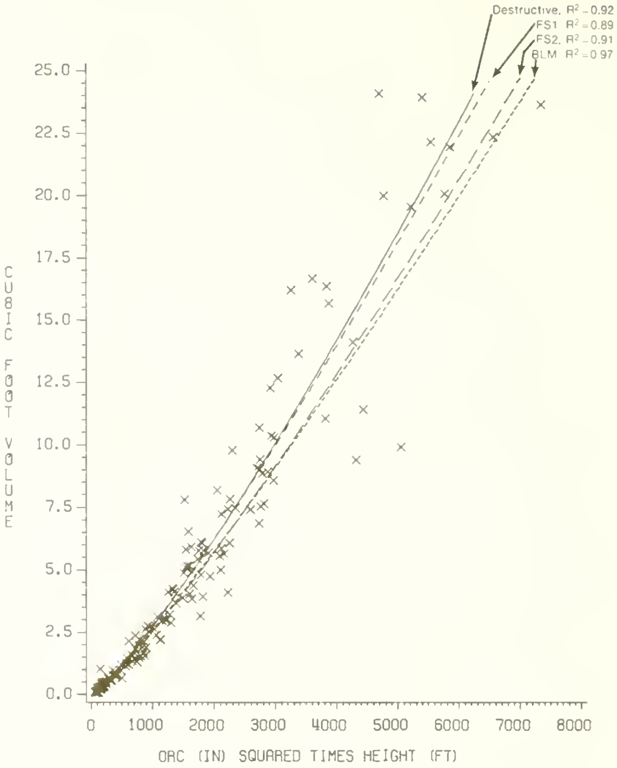


Figure 4.—Pinyon destructive segmentation data in cubic feet with a regression curve (solid line) and three curves for visual estimates overlaid.

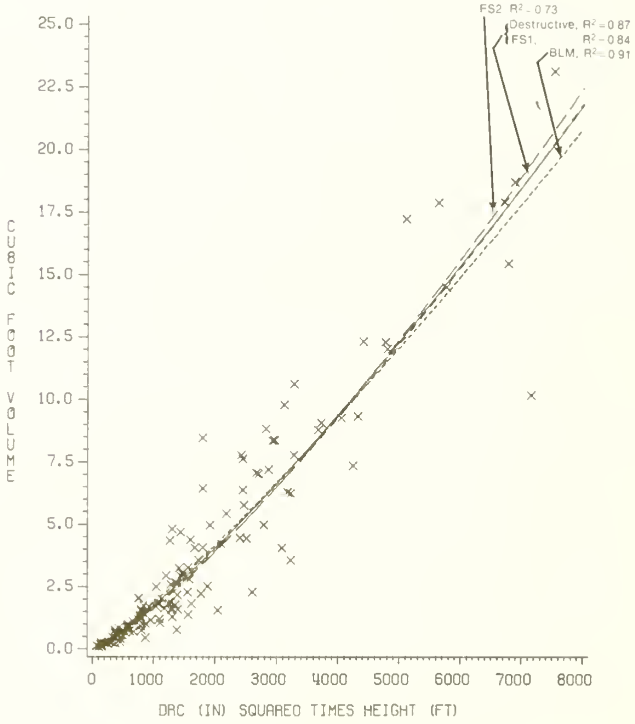


Figure 5.—Juniper destructive segmentation data in cubic feet with a regression curve (solid line) and three curves for visual estimates overlaid.

An Application

Even a small volume bias can compound rapidly when summing many trees in an inventory. An additional data set was used to examine the bias observed in the volume equations in figures 2 to 5. We used 176 plots of 0.1 acre each from the Schell Resource Area of the Ely, NV, BLM District, to compare predictions of the volume equations for the estimator groups. The plots were taken from a systematic grid at a sampling fraction of 0.1 acre for each 6,177 acres. The Schell data are within the sample population for this study and include the same two pinyon and juniper species.

Table 3 shows a summary for average cubic foot volume per acre (computed from the four equations in figs. 4 and 5) for the Schell Resource Area. The mean volumes per acre for each estimator look reasonably similar. However, most of the per-acre means, computed from volume equations based on visual data, underestimate volume when compared to the destructive equations. Overall, a negative bias as high as −9 percent (for pinyon, for BLM and FS2) resulted from using visual segmentation as opposed to destructive segmentation for estimating population means. Results tended to be better for juniper than for pinyon.

DISCUSSION

Should visual segmentation be used in a woodland inventory to estimate volume? This study shows it is a useful technique, but, like any subjective method, it should be used with caution. Estimators tend both to overestimate and underestimate volumes visually, with underestimates more common. Juniper fared better than pinyon, perhaps because juniper trees usually have more segments per tree than do pinyon. From the theory behind visual segmentation, more segments per tree give the technique higher probability of success (see equation 2). Applications of visual segmentation to real data showed a 0 to −9 percent bias in estimating mean volume per acre.

Perhaps doing more than one visual estimate per tree for fewer trees would be an effective way to reduce the bias rather than estimating many trees once. Table 4 shows the improvement by grouping estimates. The median or mean of three estimates appears to be the best for the Nevada data.

The theory behind visual segmentation appears sound, based on the good results from estimator FS1. However, the less consistent performance of the BLM estimator is probably closer to production mode reality. But with proper quality control, visual segmentation is certainly worth consideration. Our more recent experience indicates that intense training, consistent use of the segment poles, and quality control checks on estimators significantly improves the quality of the visual data.

We would like to make a final point somewhat unrelated to this study but important for application of visual segmentation to volume equation construction. Even if the bias from visually measuring pinyon-juniper volume was entirely eliminated, the procedure would not be completely satisfying for developing volume equations. This is because the relationship between pinyon-juniper tree volume and easily measured variables is not well understood.

Table 3.—Summary of 176 forested plots from the Schell Resource Area of the Ely BLM District. Volumes for each tree were computed using volume equations developed for each estimator group

Species	Diameter class	Volume per acre				Sampling error[1]	Percent of plots having trees[2]
		BLM	FS1	FS2	Destructive		
	Inches	*Ft³*				*Percent*	
Juniper	3 - 6.9	9.8	8.0	7.5	8.6	±22	68
Juniper	7 - 10.9	37.4	33.6	32.6	35.2	±22	65
Juniper	11 - 14.9	52.1	49.5	49.1	50.9	±19	57
Juniper	15 - 18.9	69.7	69.4	70.1	70.3	±22	46
Juniper	>19	131.3	138.5	142.9	137.8	±28	38
Juniper	Total	300.3	299.0	302.2	302.8	±17	89
Pinyon	3 - 6.9	32.4	33.2	30.0	31.9	±21	78
Pinyon	7 - 10.9	76.3	81.6	74.4	81.0	±21	64
Pinyon	11 - 14.9	70.4	77.6	71.2	78.6	±28	38
Pinyon	15 - 18.9	55.2	62.3	57.5	64.1	±38	19
Pinyon	>19	26.1	29.8	27.6	30.9	±56	7
Pinyon	Total	260.4	284.5	260.7	286.5	±18	84
Pinyon and juniper	Total	560.7	583.5	562.9	589.3	±13	100
		Volume Bias[3] as Compared to the Destructive Equation					
Juniper	Total	-1%	-1%	0%		±17	89
Pinyon	Total	-9%	-1%	-9%		±18	84
Pinyon and juniper	Total	-5%	-1%	-4%		±13	100

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[1] The sampling error is a t-statistic confidence interval, expressed as a percent of the sample mean, that contains the population mean unless a 1-in-20 chance occurs in selecting the sample. The errors were the same for all four volume estimates in a diameter class.

[2] This refers to the percentage of plots having trees for that diameter class. The volume was set to zero in the variance computation for the plots having no trees in a given diameter class.

[3] Bias is defined as a visual estimate (BLM, FS1, or FS2) minus the destructive estimate, divided by the destructive estimate.

Table 4.—Effect of grouping several visual volume estimates for a tree, pinyon and juniper are combined

Diameter class	Mean of FS1 and FS2[1]	Mean of FS1, FS2, and BLM	Median of FS1, FS2, and BLM	Range of percent errors for single estimates[2]
3 - 6.9	−0.003 [−1%] 76	0.006 [1%]35	−0.008 [−1%]35	−8 to 7
7 - 10.9	−.141 [5%]111	−.070 [−2%]50	−.223 [−7%]50	−10 to 0
11 - 14.9	−.894 [−11%] 66	−.455 [6%]38	−.688 [−9%]38	11 to −5
15 - 18.9	.068 [1%] 35	.521 [4%]18	.484 [3%]18	−11 to 2
>19	−1.422 [5%] 14	.417 [2%] 8	.350 [−1%] 8	−8 to −1

[1] Mean visual volume difference, followed in brackets by mean difference expressed as a mean percent of destructive volume, followed by sample size

[2] This is the range of errors corresponding to the value in brackets for FS1, FS2, and BLM kept separately.

For example, our volume equation using destructive segmentation had rather large confidence intervals. The confidence bands in figures 2 and 3 correspond to roughly ±40 and ±50 percent of the predicted cubic foot volume for a single pinyon and juniper, respectively. This implies much variation in the data. As a result, our volume equation coefficients are the best "least squares" coefficients for the mix of diverse tree forms in our sample data. A slightly different mix of tree forms could result in much different regression coefficients. In other words, we suggest that volume equations based on visual segmentation only be used in the local areas where the segmentation data were collected. This practice will reduce the probability of extrapolation errors from use of an inappropriate volume equation. The ease and simplicity of the visual segmentation procedure allows the option to develop new volume equations or at least check existing equations for use in any woodland inventory or cruise.

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APPENDIX: WOODLAND TREE VISUAL SEGMENTATION PROCEDURE

This appendix contains a field procedure for visually estimating cubic foot volume of woodland tree species. The procedure is updated slightly over that used for the data collected in this study. The main difference is that the segment length classes were changed from 2-foot to 1-foot intervals. Species included for the Rocky Mountain States are all hardwoods except aspen and cottonwood, and pinyon and juniper softwoods.

What To Segment

Trees to be measured for volume must have at least one live stem 3 inches or larger in diameter at the root collar (DRC) measurement point. A stem, as opposed to a branch, generally grows in an upright position and contributes to the main structural support of a tree crown. All stems, branches, and bark, whether live or dead, are included. Even severed branches lying on the ground are measured. If a tree portion is missing (from fencepost cutting, firewood cutting, and so forth), estimate the size of the missing portion and record the missing segments. Omit a tree if more than half is missing or if it is unreasonable to estimate the missing parts.

A woodland tree is defined as a woodland species capable of yielding at least one stem 3 inches or larger DRC with at least 8 feet of wood meeting minimum segment size standards. Tree species not meeting these specifications are considered brush form and are not inventoried as trees.

In practice, trees meeting the specifications must presently or potentially stock an area of at least 1 acre surrounding a sample plot for the vegetation to qualify as forest. Present stocking of tree form vegetation, or evidence of prior stocking, must exceed 10 percent crown cover for minimum stocking, and each individual species must have the potential to meet tree form specifications for the species to be included.

What Is a Segment?

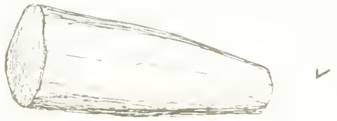
A segment is a piece of wood classified by midpoint of length and diameter. The 1-foot length and 2-inch diameter classes are:

1-foot length classes		2-inch diameter classes	
Midpoint class	Actual lengths	Midpoint class	Actual diameters (outside bark)
1	1-1.49	2	1.5- 2.9
2	1.5-2.49	4	3- 4.9
3	2.5-3.49	6	5- 6.9
4	3.5-4.49	8	7- 8.9
5	4.5-5.49	10	9-10.9
6	5.5-6.49	12	11-12.9
		14	13-14.9
		16	15-16.9
		etc.	

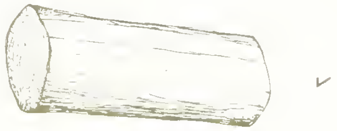
The field estimator chooses the actual segment dimensions by visually dividing stem and branch wood into consecutive lengths for classification. Success of the segmentation procedure is completely dependent upon the good judgment and care exercised by the estimator.

To qualify, a segment must be at least 1.5 inches at midpoint diameter, 1.5 inches at the small end diameter, and 1 foot in total length. Unless the segment is a cylinder, the minimum midpoint diameter will be larger than 1.5 inches. Segments may be any diameter (class), but lengths are limited to 6 feet maximum to minimize errors in estimating dimensions and in computing volume.

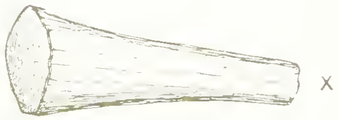
As a rule of thumb, segments should be selected so they approximate a paraboloid frustum or a cylinder. Avoid breaking a stem or branch into segments that look like neiloid or cone frustums.



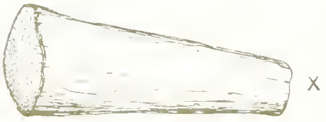
PARABOLOID FRUSTUM



CYLINDER



NEILOID FRUSTUM



CONE FRUSTUM

When in doubt, always select short segments (<3 feet) because they will minimize errors due to odd shapes when calculating volume. Keep in mind that length class spans a 1-foot interval and the diameter class spans a 2-inch interval. For greatest accuracy, choose segment lengths as close to the class midpoint as possible. Occasionally segments must be "adjusted" to fit length categories by mentally moving sections from one segment to an adjacent segment. This is likely to occur around forks or other abrupt changes in segment form. Care must also be exercised when classifying lengths of segments from branches originating at angles less than 45 degrees. The length class should be the average length of the upper and lower sides.

How To Segment

A systematic method is used to (1) avoid omitting segments and (2) avoid recording a segment more than once. Begin visual segmentation on the main stem at the ground line. On multiple stem trees, begin segmentation with the smallest DRC stem. Proceed up the stem until you encounter a branch that contains a qualifying segment(s) or the stem forks. Make sure all branches having

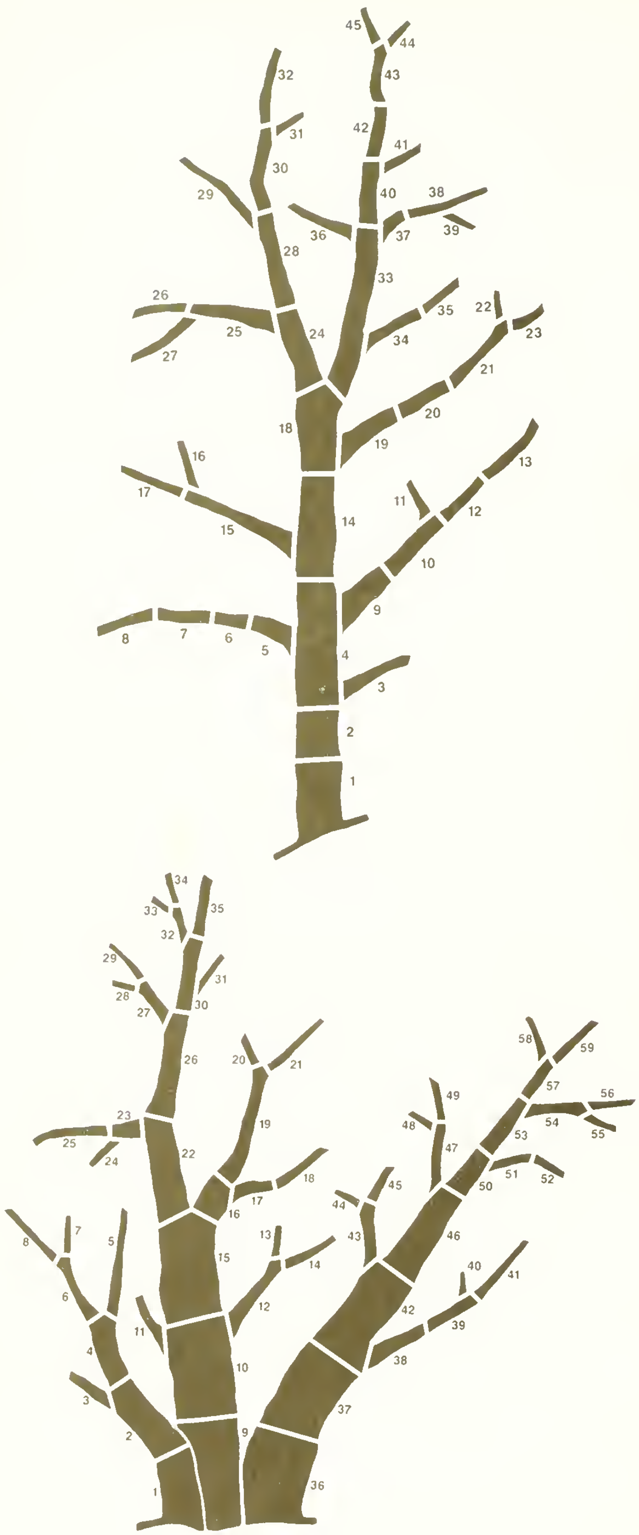


Figure 6.—The order of segment tallies.

a 1.5-inch minimum diameter that qualify as segments are counted as you proceed up a stem. Do not back up and guess the size of small segments after all large stems have been tallied (previous estimators have made large errors by miscounting small segments). Whenever a fork is encountered, always proceed up the smaller stem first, then return to the fork and proceed up the larger stem.

Figure 6 contains diagrams illustrating the order of tallying segments. The numbers indicate the order of tallying.

Field Estimation of the Segments

Classification of the segments is best done with aid of "segment poles," 1-inch square aluminum tubes 5 feet long, scaled with colored tape (see fig. 7). (The segment poles are a modification of McClure's [1968] tree height poles.) Red 1-foot and yellow ½-foot marks on the poles aid the estimation of segment lengths. Alternating yellow and black 2- and 4-inch wide bands at the pole's base aid in estimating segment diameters. A segment pole is placed against the lower stem and branches (where most of the wood is found) for correct length classification. A peg in one end of each pole permits the poles to be connected together and placed upward into a tree crown. Also, use of the segment pole should eliminate diameter misclassification of segments within the lower portion of the tree. The midpoint diameters of large segments (10 inches and larger) that are within reach should be measured with a diameter tape.

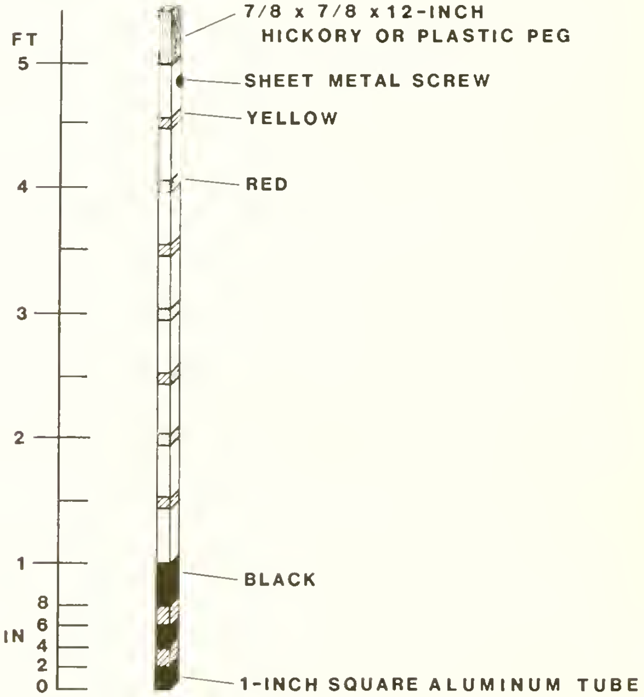
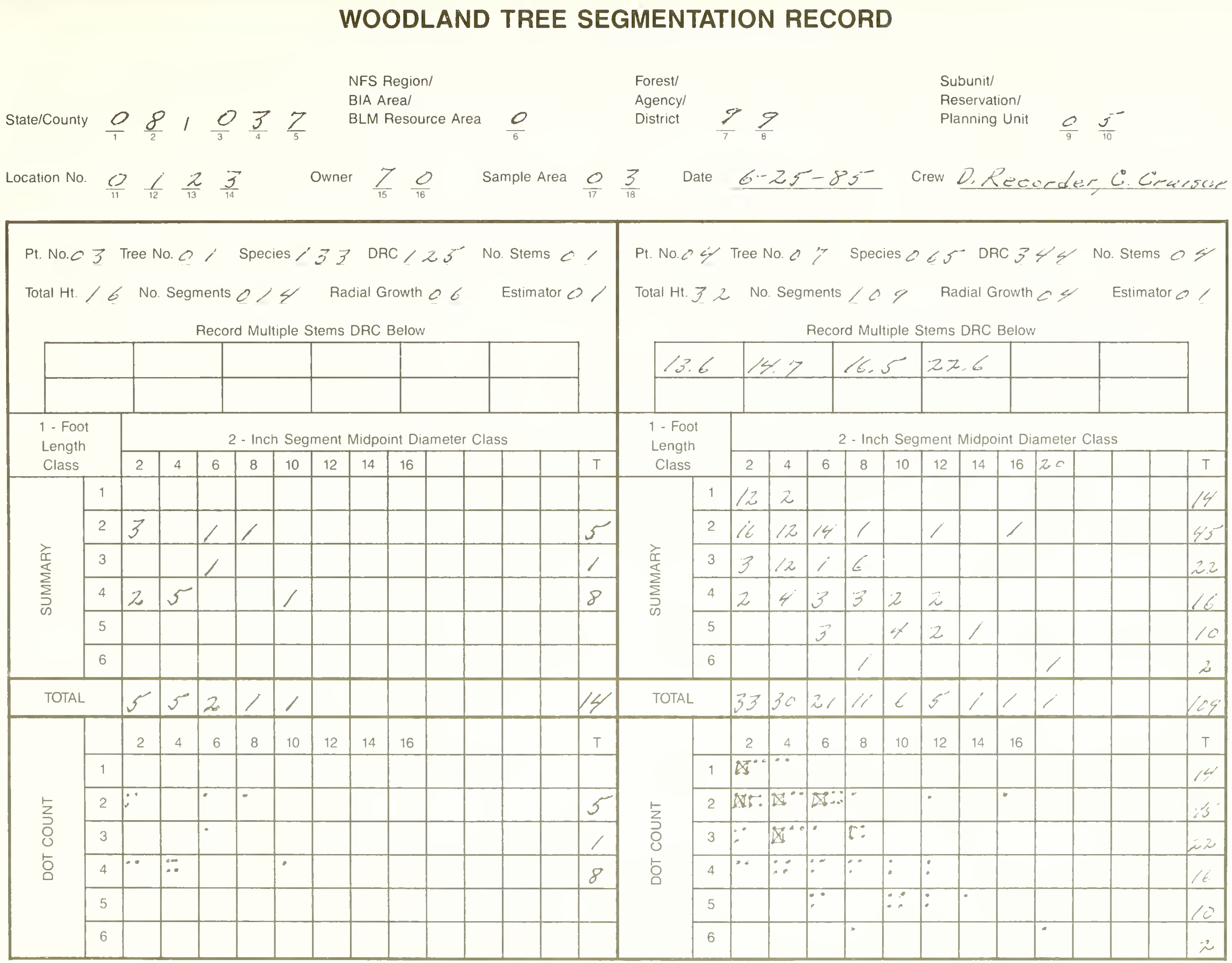

FT
5
4
3
2
1
IN
8
6
4
2
0
7/8 x 7/8 x 12-INCH HICKORY OR PLASTIC PEG
SHEET METAL SCREW
YELLOW
RED
BLACK
1-INCH SQUARE ALUMINUM TUBE

Figure 7.—A construction diagram for a "segment pole" made of 1-inch-square aluminum tubing.

How to Record Segments

Tally segments on the tree segmentation form by using the dot count method (see fig. 8). Blank forms at the end of this publication are included for use by the reader. For segments with diameters larger than 16



WOODLAND TREE SEGMENTATION RECORD

State/County 0 8 / 0 3 7 (1 2 3 4 5)
NFS Region/BIA Area/BLM Resource Area 0 (6)
Forest/Agency/District 9 9 (7 8)
Subunit/Reservation/Planning Unit 0 5 (9 10)

Location No. 0 1 2 3 (11 12 13 14)
Owner 7 0 (15 16)
Sample Area 0 3 (17 18)
Date 6-25-85
Crew D. Recorder, C. Cruiser

Pt. No. 0 3 Tree No. 0 1 Species 1 3 3 DRC 1 2 5 No. Stems 0 1
Total Ht. 1 6 No. Segments 0 1 4 Radial Growth 0 6 Estimator 0 1

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2	3		1	1									5
	3			1										1
	4	2	5			1								8
	5													
	6													
TOTAL		5	5	2	1	1								14
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													5
	3													1
	4													8
	5													
	6													

Pt. No. 0 4 Tree No. 0 7 Species 0 6 5 DRC 3 4 4 No. Stems 0 4
Total Ht. 3 2 No. Segments 1 0 9 Radial Growth 0 4 Estimator 0 1

Record Multiple Stems DRC Below

13.6	14.7	16.5	22.6		

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16	20				T
SUMMARY	1	12	2											14
	2	16	12	14	1		1		1					45
	3	3	12	1	6									22
	4	2	4	3	3	2	2							16
	5			3		4	2	1						10
	6				1					1				2
TOTAL		33	30	21	11	6	5	1	1	1				109
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													14
	2													45
	3													22
	4													16
	5													10
	6													2

Figure 8.—An example of segmentation recording form.

inches, blank spaces are provided to specify the correct 2-inch diameter class, such as 18, 20, 22, or 24. When a tree has been completed, summarize the dot counts in the space provided. Total all columns and rows and enter this figure under heading TOTAL (T). Also enter the grand total segment count in the header information.

Definitions

DRC.—The diameter to the nearest 0.1 inch of a tree at just above the root collar or ground line. DRC is measured at the ground line for single-stem trees with uniform stem taper. If a tree forks near or below the ground line, a DRC of each stem is measured and an equivalent DRC (EDRC) is computed and recorded in place of DRC:

$$\mathrm{EDRC} = \sqrt{\sum_{i=1}^{n} \mathrm{DRC}_i^2}$$

where

n = number of stems

DRC_i = diameter of the ith stem.

Although a tree must have at least one stem 3 inches DRC or larger to be segmented, the EDRC computation may include stems less than 3 inches DRC if these stems support qualifying segments. Space is provided for recording multiple diameters for later calculation and for checking the data.

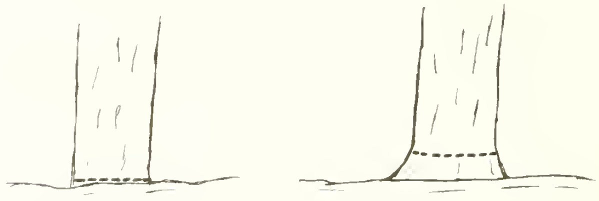
Situations often occur that require judgment in determining the point of diameter measurement. DRC or EDRC is used to compute the basal area of stems supporting the total stem and branch volume of a tree. Thus, DRC or EDRC should be measured at the lowest point on a tree where it best represents the basal area supporting that tree. In other words, the measurements should be taken at the lowest point consistent with the taper of the stem(s) in a tree. Do not include butt swell or other abnormalities that will increase the diameter over that taken at the base of a stem(s) with uniform taper. Move the measurement point up the tree as needed to obtain a reasonable measurement.

When a tree forks near the base, EDRC should be computed from the stems above the fork if a single measurement near the base would obviously inflate the value. A tree forking just above the ground could often be measured at the base as a single-stem tree, but space between the stems will usually inflate the measurement. On the other hand, moving too far up a tree to measure stems above a fork could give an unreasonably small measurement to represent the base of that tree. See figure 9 for examples of DRC and EDRC measurement points.

No. stems.—A count of the number of basal stems used for DRC or EDRC measurements. Stems, as compared to branches, provide structural support for a major portion of a tree.

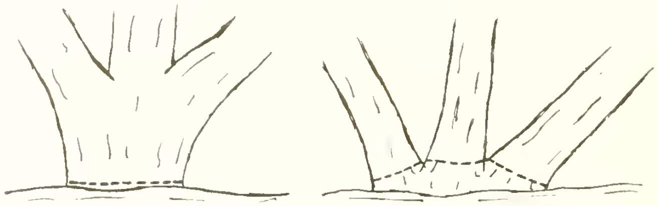
Qualifying segment.—A piece of wood at least 1 foot long and at least 1.5 inches in diameter (outside bark) at the small end.

Total ht.—The total height of a tree measured perpendicular to the ground line to the nearest 1 foot. For multiple-stem trees, the height of the tallest stem is measured.



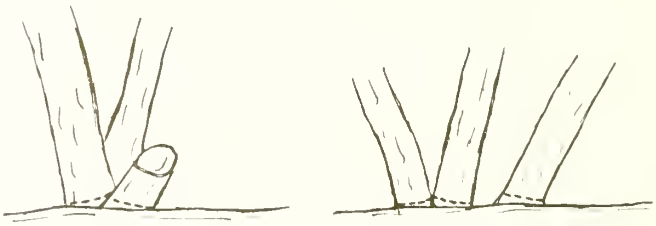
Measure at ground line when reasonable.

Measure above butt swell.



Measure DRC at base when representative of total basal area.

Measure individual stems when DRC excessive. Compute EDRC.



Measure cut stems. Include in EDRC.

Measure individual stems at ground line. Compute EDRC.

Figure 9.—Examples of DRC and EDRC measurements.

WOODLAND TREE SEGMENTATION RECORD

State/County ___ ___ / ___ ___ ___
1 2 / 3 4 5

NFS Region/
BIA Area/
BLM Resource Area ___
6

Forest/
Agency/
District ___ ___
7 8

Subunit/
Reservation/
Planning Unit ___ ___
9 10

Location No. ___ ___ ___ ___
11 12 13 14

Owner ___ ___
15 16

Sample Area ___ ___
17 18

Date ________

Crew ________

Pt. No. ___ Tree No. ___ Species ___ DRC ___ No. Stems ___

Total Ht. ___ No. Segments ___ Radial Growth ___ Estimator ___

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. ___ Tree No. ___ Species ___ DRC ___ No. Stems ___

Total Ht. ___ No. Segments ___ Radial Growth ___ Estimator ___

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
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	5													
	6													

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

WOODLAND TREE SEGMENTATION RECORD

State/County __ __ / __ __ __ (1 2 / 3 4 5)

NFS Region/
BIA Area/
BLM Resource Area __ (6)

Forest/
Agency/
District __ __ (7 8)

Subunit/
Reservation/
Planning Unit __ __ (9 10)

Location No. __ __ __ __ (11 12 13 14)

Owner __ __ (15 16)

Sample Area __ __ (17 18)

Date ________

Crew ________

Pt. No. __ Tree No. __ Species __ DRC __ No. Stems __

Total Ht. __ No. Segments __ Radial Growth __ Estimator __

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class											
		2	4	6	8	10	12	14	16				T
SUMMARY	1												
	2												
	3												
	4												
	5												
	6												
TOTAL													
DOT COUNT		2	4	6	8	10	12	14	16				T
	1												
	2												
	3												
	4												
	5												
	6												

Pt. No. __ Tree No. __ Species __ DRC __ No. Stems __

Total Ht. __ No. Segments __ Radial Growth __ Estimator __

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class											
		2	4	6	8	10	12	14	16				T
SUMMARY	1												
	2												
	3												
	4												
	5												
	6												
TOTAL													
DOT COUNT		2	4	6	8	10	12	14	16				T
	1												
	2												
	3												
	4												
	5												
	6												

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
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	6													
TOTAL														
		2	4	6	8	10	12	14	16					T
DOT COUNT	1													
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	4													
	5													
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Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
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TOTAL														
		2	4	6	8	10	12	14	16					T
DOT COUNT	1													
	2													
	3													
	4													
	5													
	6													

Born, J. David; Chojnacky, David C. Woodland tree volume estimation: a visual segmentation technique. Research Paper INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 16 p.

Visual segmentation, a technique for estimating cubic foot volume of woodland tree species, was compared with actual volume measurement. Results indicate that visual segmentation data are useful for developing volume equations.

KEYWORDS: pinyon, juniper, inventory

The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station's primary area includes Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

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Ogden, Utah

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U.S. GOVERNMENT PRINTING OFFICE: 1985—576-040 20,000 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-345

June 1985

Visitor Characteristics, Attitudes, and Use Patterns in the Bob Marshall Wilderness Complex, 1970-82

Robert C. Lucas

CLEMSON UNIVERSITY
SEP 5 1985

THE AUTHOR

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RESEARCH SUMMARY

Visitors to the Bob Marshall Wilderness complex, which includes the Bob Marshall Wilderness, the Great Bear Wilderness, and the Scapegoat Wilderness, were studied in 1982 as they also had been studied in 1970. Questionnaires were basically identical, and were returned by over 500 visitors in 1970 and by almost 800 in 1982. Both summer and fall use were studied.

The major change was a shift from predominantly horse use in 1970 to mainly backpacker use in 1982. Both horse and hiker use increased, but hiker use grew much faster than horse use. Many other changes seemed to stem from this basic shift: shorter stays, smaller parties, a smaller proportion of visits with outfitters, some shift in activities from more consumptive to more contemplative, more summer and less fall use, and less dependence on wood fires. Other changes in use were: less weekend peaking and less concentrated use. These changes imply lower potential for impacts to resources on a per-party basis.

Most visitor characteristics remained about the same or changed only moderately from 1970 to 1982. The essentially unchanged characteristics included urban/rural residence, type of social group, age distribution, high levels of overall wilderness experience, and club membership. Modest changes from 1970 to 1982 included more visitors from out of State, more women, higher educational levels, more visitors in professional and technical occupations, and less previous experience in the Bob Marshall complex, especially for backpackers. These changes also reflect the shift to more backpacker use. Many changes in visitor characteristics seem to point to slower future growth in use.

In a few cases attitudes shifted sharply, in contrast to general stability in attitudes. Complaints about trails were six times as common in 1982 as in 1970, and support for high standard trails and bridges grew. Support for allowing some natural forest fires started by lightning to burn also increased. Crowding and conflict, particularly dissatisfaction among hikers with horse use, were mentioned more. Reasons for visiting wilderness shifted, paralleling the shift from more consumptive use (hunting, fishing) to more contemplative (enjoying scenery, relaxation, escaping civilization), but solitude and avoidance of mechanized recreation were important reasons both years. Numbers of other visitors met per day grew moderately, and accounted for about 45 percent of the variation in opinions of numbers met (too many, too few, etc.). Satisfaction levels were about the same both years, but were negatively associated with numbers met per day. With the single striking exception of desiring improved trails, visitors became more opposed to facilities and more supportive of actions to preserve natural ecosystems, and supported minimum impact use practices more. Littering was thought to be reduced, but vegetation and soil impacts were seen as worse. Desired campsite solitude was usually found, but less often in 1982 than in 1970. There was little or no change in the importance visitors attached to wilderness, factors satisfying visitors, feelings of crowding, campsite solitude standards, and attitudes about most existing and potential regulations.

The trends in recreational use in the Bob Marshall complex offer managers time to deal with problems without being overwhelmed by rapidly escalating use and impacts. Trail deterioration is the top priority problem, followed by campsite impacts and horse-hiker conflicts. High education levels and personal commitment to wilderness suggest that education would be an effective management tool. Most visitors believe the Bob Marshall complex still provides a high-quality wilderness experience that deserves to be protected by managers.

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Visitor Characteristics, Attitudes, and Use Patterns in the Bob Marshall Wilderness Complex, 1970-82

Robert C. Lucas

INTRODUCTION

Effective planning for the management of outdoor recreational use requires not only knowledge of the current situation but also indications of the dynamics of change. Without some grasp of the nature of recreational use, and of visitor characteristics, behavior, satisfactions, attitudes, and preferences, and how they are changing, at least in general terms, management often will be misdirected and inefficient. Attention is likely to be focused on old problems, vaguely defined, some of which may have actually faded away, others of which may have intensified, and some of which have evolved into different issues.

WILDERNESS TRENDS

Wilderness management suffers particularly from the lack of information on visitor use and dynamics. Compared to most types of recreation, wilderness visitors are more widely dispersed, use is relatively light, and observation and contact by managers are limited. Furthermore, the wilderness experience is complex and subtle, with many important features that are not outwardly observable; for example, visitor evaluations of levels of solitude or crowding experienced.

Finally, many wilderness managers seek to be as light-handed and nonregulatory as possible, using information and education as major management techniques. Several studies suggest that visitors prefer information and education approaches over regulatory styles of management (Stankey 1973; Lucas 1980, 1983). This nonregulatory approach requires information about visitors' behavior, knowledge, experience, attitudes, and preferences to be well designed and focused, particularly because of the controversy that often surrounds many wilderness management decisions. Any evaluation of the effectiveness of management actions, both regulatory and nonregulatory, requires some information on changes—or lack of changes—in the relevant visitor characteristics. For example, if managers encourage visitors to use campstoves instead of wood fires, does the proportion using stoves increase? If managers strive to disperse campers at attraction sites, does this happen and do campers perceive more campsite solitude? If they attempt to reduce party size, do they succeed?

Trends can be analyzed for a variety of aspects of recreational use: amount of use, types of use, visitor activities, characteristics, and so on. Amount of use is probably the easiest to measure, although in fact the basic use data for most wildernesses are of such low accuracy that trends are difficult to identify, with estimation errors usually overwhelming actual changes. Trends in wilderness participation have been analyzed, primarily at a nationwide level, for National Forest Wilderness (Petersen 1981). The average annual rate of growth in use from 1965 has been about 4 percent, with lower rates more recently than earlier, and somewhat faster growth in newly designated wilderness than in areas established earlier.

Trends in the characteristics of wilderness use and users are harder to measure, requiring a visitor survey for most characteristics. Perhaps because of this difficulty, these trends have been little studied. Only four related studies were found. One was based on repeat surveys of visitors to the Allagash River in Maine (Cieslinski 1980). Three surveys were conducted, but the first, in 1966, is not comparable with those in 1973 and 1975. Data for only eight variables were reported, and only use by large parties changed substantially, declining over the 2 years. Data from mandatory permits showed use more than doubling from 1966 to 1979, while parties became smaller and stays shorter.

The second was a study of recreational use of the Rattlesnake area north of Missoula, MT, a National Forest area which was designated partly as a National Recreation Area and partly as wilderness in 1980 (Corti and others 1982). Use measurements were made in 1977 and 1981. Total use declined but use of the wilderness grew moderately and groups became smaller. Questionnaire surveys were also conducted in 1978 and 1981. There were no changes in the distribution of male and female visitors, occupations, or education, and only a slight tendency for 1981 visitors to have less previous experience in the area than 1978 visitors.

A third study was concerned mainly with the effects of use limits on visitation to the backcountry in Yosemite National Park, but included some data on trends in use patterns and visitor characteristics (Van Wagtendonk 1981). Total use rose rapidly to 1975, but declined a little from then to 1979, apparently not because of use rationing, which began in 1974. Age and education data from two separate surveys only a few years apart (1973 and 1975-76) (not repeat surveys focused on trends), showed little change in age, education, and income, but the proportion of female visitors increased. There was no trend in either party size or length of stay. Perhaps because of use limits, more people visited before and after the peak month of August, and also spread out a little more evenly.

The fourth study analyzed changes in the Boundary Waters Canoe Area in Minnesota from 1961 to 1966 (Lucas 1967). Paddling canoeists and boat campers increased the most, and use became less geographically concentrated. More visitors came from outside Minnesota in 1966 than 1961. Parties became slightly larger, but stays became shorter.

Wilderness use has grown greatly since passage of the Wilderness Act in 1964, public environmental attitudes seem to have changed, and a new generation has entered the scene. Yet, beyond a general feeling that numbers of visitors have been increasing, most wilderness managers are forced to operate with not much more than guesses and speculation about changes in the characteristics of the wilderness visitors, what they do, how they do it, and what they think about wilderness, about area conditions, or about present or potential management actions.

BOB MARSHALL TREND STUDY

In 1982, visitors to the Bob Marshall complex were studied, as they also had been in 1970 (Lucas 1980). The main objective was to determine trends in characteristics of use, use patterns, visitor experiences, characteristics and attitudes about the wilderness and its management. The Bob Marshall complex consists of three contiguous National Forest Wildernesses—the Bob Marshall, the Great Bear, and the Scapegoat—on both sides of the Continental Divide in the Rocky Mountains south of Glacier National Park (fig. 1). The Bob Marshall contains 1,009,000 acres (408 000 ha), the Great Bear 287,000 acres (116 000 ha), and the Scapegoat 239,000 acres (97 000 ha), for a total in the complex of a little over 1½ million acres (over 600 000 ha), or over 6 percent of all the wilderness acres in the National Forests at the time of the study. The three areas are described further in Lucas (1980).

All three areas were included in both the 1970 and 1982 studies. Although the Great Bear and Scapegoat were designated as wildernesses after the 1970 study, the Scapegoat in 1972 and the Great Bear in 1978, the same major access points were covered then as in 1982, thus creating no data comparability problems. Designation may have contributed to some changes in addition to the passage of time (Petersen 1981; McCool 1984). In 1982, some additional lightly used access points were sampled. Because use at these accesses was light, samples there were small, and overall data were little affected.

Most of the information collected in 1970 was repeated in identically worded questions in 1982. A few items that seemed low in priority were not repeated; for example, a question on income was dropped. A few new topics were investigated in 1982; for example, how people chose trailheads and campsites. Generally, these one-time data are not reported in this paper, which is focused on trends in these three wildernesses.

The studies in both years were designed to describe accurately the characteristics of use and users, not to estimate total use, and conclusions about trends in total use cannot be drawn from the study. Official agency estimates of total annual recreational use were 263,400 recreation visitor-days (based on 12-hour days) in 1982

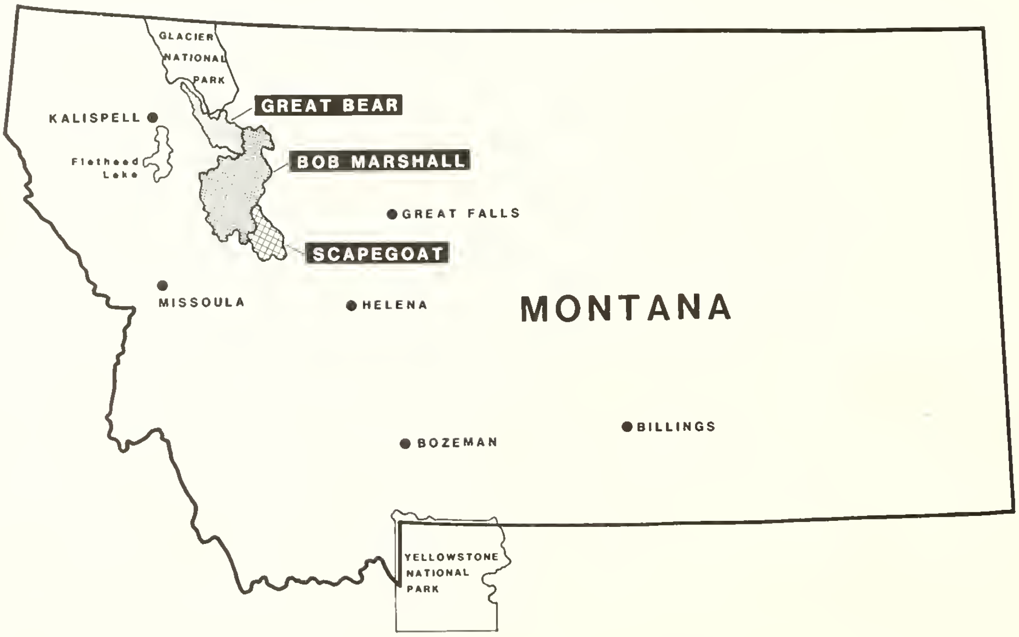

Figure 1.—Location of the Bob Marshall, Great Bear, and Scapegoat Wildernesses.

for the complex. Estimated use of the Bob Marshall Wilderness grew from 114,500 visitor-days in 1970 to 178,200 in 1982, a 56 percent increase, or about 4 percent per year. Use estimates for the Scapegoat Wilderness were first available for 1973; use since then has grown from 16,400 to 27,900 visitor-days in 1982, a 70 percent increase in 10 years. The Great Bear Wilderness shows a 159 percent increase from 22,100 to 57,300 visitor-days from 1979 to 1982, with almost all of growth in estimated use occurring from 1981 to 1982. At least a 60 percent increase for the complex seems indicated by these official use estimates.

METHODS

Methods were essentially the same in both years. More detail on the 1970 methods is contained in Lucas (1980). Survey research adapted to the wilderness situation was the basic method.

Source of Samples

The study population was all adult visitors (defined as anyone 16 years old or older) entering the three areas in summer and fall. The basic method was personal contact of visitors, supplemented by temporary special registration stations.

Field workers—three in 1982, one in 1970—contacted all visitors entering or leaving at 34 trailheads on selected sample dates. (Sampling procedures are described below.) They briefly explained the study, and asked visitors 16 and older voluntarily to provide their names and addresses so that some of them could be selected for a mail questionnaire about their trip and their ideas about wilderness. In 1982, personal contact was used at all trailheads estimated by managers to average at least five visitors per week. In 1970, personal contact was used in the Bob Marshall, Great Bear, and at the major trailhead serving the Scapegoat Wilderness. Visitor cooperation was complete in 1970 and there was only one refusal in 1982.

Special portable trail registers were used in 1982 at 14 trailheads estimated to average at least one but less than five visitors per week. The same trail registers were used in 1970 at all Scapegoat Wilderness trailheads except the one main one (Indian Meadows), which was sampled by personal contact.

The special trail registers (fig. 2) explained that a study was in progress, asked visitors at least 16 years old to register as individuals (not just the group leader), and provide full mailing addessses. Cooperation was excellent. Field checking in 1970 indicated registration rates of 94 percent for hikers and 67 percent for visitors with horses. Informal observation in 1982 suggested similar high registration rates.

In both study years, visitors who entered at trailheads were included whether they crossed a wilderness boundary or not. Most sampled visitors entered the Bob Marshall in 1970 (the only area that had wilderness status then and an established boundary) and entered one of the three wildernesses in 1982.

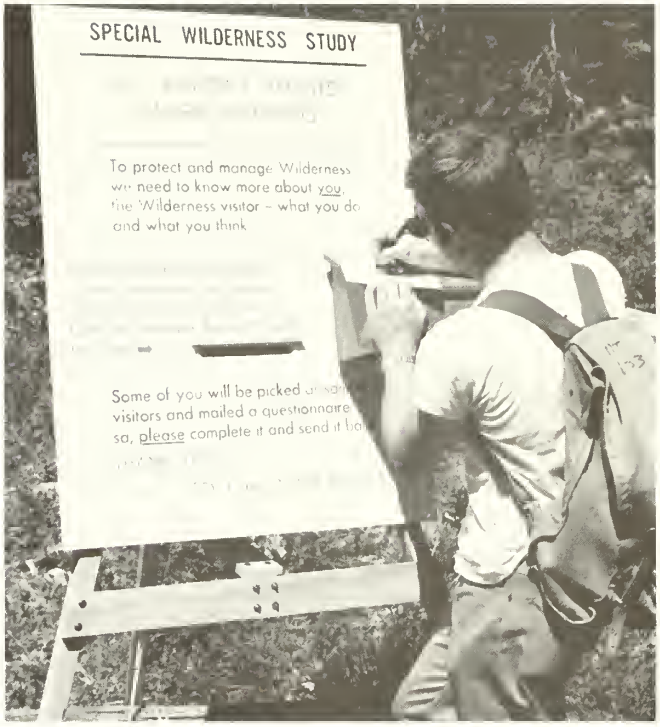
SPECIAL WILDERNESS STUDY
To protect and manage Wilderness we need to know more about you, the Wilderness visitor – what you do and what you think
Some of you will be picked as visitors and mailed a questionnaire so, please complete it and send it ba

Figure 2.—The special trail registers placed at the lightly used trailheads in 1970 and 1982.

Mail Questionnaire Procedures

Names and addresses of selected visitors were entered in two lists. One list was in questionnaire serial number order. It was used to log in returned questionnaires and to prepare followup mailings. In 1970, up to five questionnaires, each with a different cover letter, were mailed at 2- to 3-week intervals to visitors sampled. In 1982, following procedures suggested by Dillman (1978), nonrespondents were sent a reminder postcard after 3 weeks, and, if no response was received, another questionnaire and cover letter were mailed 3 weeks later. Rates of return, a principal concern with mail surveys, were high in both years, as shown below:

	Number of questionnaires mailed	Number undeliverable	Completed and returned	Percent delivered returned
1970	552	8	502	91
1982	972	13	785	82

The main reason for the slightly lower rate in 1982 appears to be the effect of only up to three mailings in 1982 compared to up to five mailings to nonrespondents in 1970. The rate of return for the first three mailings in 1970 was 86 percent, little different from the 1982 rate of 82 percent. The questionnaire was also longer in 1982 than in 1970. The visitors who registered at the special stations in 1982 had an 83 percent rate of return, close to the 81 percent rate for the people contacted in person.

The other list of names and addresses was in alphabetical order to avoid sampling the same person repeatedly and unduly imposing on their cooperation. Less than

1 percent of the sampled persons were selected twice. They received a weight of 2. No one was selected more than twice.

Study Seasons

Sampling in 1982 began June 21 and continued with no interruptions through October 24. In 1970, sampling began a few days earlier, and ran until about November 20.

The earlier termination date in 1982 introduces some minor noncomparability. Big game hunting seasons in most of the wilderness complex began September 15 every year in the periods covered by these two studies and the October 24 termination of field work covered 5½ weeks of elk hunting activity.

Parts of the Scapegoat and Great Bear Wildernesses opened to hunting on October 24, 1982. However, a trail use measurement project in 1981, in cooperation with the National Forests managing the Bob Marshall, yielded day-by-day records of use on seven major trails on all sides of the area, and showed that use in late October and November dwindled to a low level. Hunting season dates were comparable in 1981 and 1982. Therefore, limitations on research funds resulted in a decision not to sample the few visitors anticipated in the late fall. Furthermore, in 1970, only 5 percent of the Great Bear Wilderness sample came from visits after October 24. The comparable figure for the Bob Marshall Wilderness was 4 percent, and for the Scapegoat Wilderness was only 2 percent. Thus, any possible noncomparability due to variation in dates can only be very small and cannot have any important effect on comparisons.

Sample Design

The sample design is complex, as is usually necessary in sampling wilderness visitors (Lucas and Oltman 1971). The general plan was to give every visitor to each study area wilderness the same chance to be sampled as every other visitor to the same area. In 1970 we did not try for the same intensity of sampling in each of the three areas, so samples from different wildernesses can only be combined after weighting. Within any single area, however, all visitors had an equal chance to be included in the survey. In 1982 we sampled the three contiguous wildernesses as a single area. Thus, in 1982, all visitors had an equal chance to be included, and data for the three areas can be combined without weighting.

Respondents can be classified by the areas visited and also by the primary area of the visit. Most comparisons, however, are made for the three areas as a single complex. Several factors led to this decision.

1. The aggregation of data produces more reliable estimates. The sample is much larger and less affected by the results of specific sampling schedules. It seems that results for the whole complex present much more accurate, representative data for the things measured than do data for each wilderness separately. Thus, comparisons between 1970 and 1982 are more meaningful for the entire complex than for individual wildernesses.

2. Visitors use the area as a single wilderness. Some travel through more than one of the designated wildernesses; about 6 percent of our sample did. Furthermore, some major trailheads serve two wildernesses; for example, the North Fork of the Blackfoot River trail is an important access to both the Scapegoat and Bob Marshall Wildernesses. So is the Benchmark trailhead. Schafer air field and Silvertip on the Spotted Bear River are important accesses to both the Great Bear and the Bob Marshall Wildernesses.

3. Management of the three wildernesses has become substantially unified. Four National Forests manage portions of the complex, but with coordinated planning. In fact, most of the individual wildernesses also have multiple National Forest management, so there is little difference in this regard between the complex and the areas that comprise it. The Scapegoat Wilderness is divided among three National Forests, the Bob Marshall between two, and only the Great Bear is in one National Forest.

The main sample design was a cluster sample, with paired selection of primary samples from unequal-sized clusters, with the clusters chosen with probabilities proportional to size (PPS) and subsampled with probabilities inversely proportional to size (Kish 1967, chapter 7). The PPS concept used estimates of average weekly use by the managers of each area as measures of "size." For example, imagine two trailheads, one (A) estimated to have 100 people entering per week, the other (B) estimated to have 10 per week. Trail A is 10 times as likely as B to be sampled (to receive direct trailhead checking). This sampling method means important major trails are almost sure to be sampled and guards against much time being wasted to produce few sample visitors; but it does not give every visitor an equal chance to be sampled. To achieve that, the persons whose names and addresses were obtained in each cluster at the different trailheads were then subsampled with probabilities inversely proportional to size. In the example, this means that persons on the list at A have only one-tenth the chance of being subsampled as persons at B. The probabilities proportional to size cancel out, and everyone has the same chance of being chosen in the final sample. In other words, a visitor at A is 10 times as likely as a visitor at B to have his or her name requested, but a visitor who gives his or her name at B is 10 times as likely to be mailed a questionnaire.

One reason for this seemingly roundabout procedure was to try to produce final clusters of about the same size. Equal, or at least reasonably close, cluster sizes are important to produce an efficient sample that will yield precise, unbiased estimates, given the size of the sample (Kish 1967). In the example, if one-half of the trail B people were sampled and one-twentieth of the trail A people, each cluster would consist of five people if use was what it was estimated to be. Variation between actual use for a sample time period compared to the estimated use introduces unavoidable variations in cluster size, of course.

Trails were chosen from summer and fall strata. In 1970, groups of weeks were used as the basic time unit for sample selection. In 1970 the sample selection formulas yielded 40 clusters, each with a planned-for average size of about 12 people. In 1982 there were 74 clusters, based on 4-day weekday periods (Monday through Thursday) and 3-day weekends (Friday through Sunday), with a planned size of 10 people each.

There were some exceptions to this procedure in 1970. In the Bob Marshall and Great Bear Wildernesses, because first-stage sampling produced small samples, everyone contacted was sampled. This means the samples for these areas tend to overrepresent visitors who entered at what were estimated to be more heavily used entries. In 1982 the special registration signs at lightly used trailheads for the supplemental sample were in place continuously, resulting in a greater chance for these visitors to become involved in the survey than those contacted in person. Half of these registrants were sampled and, to avoid overrepresenting them, their responses were weighted down to provide equal representation with the basic cluster sample.

Because of differences between estimated use and actual use and chance variations, sample sizes varied from the sample-design goals to varying degrees (table 1).

Table 1.—Sample sizes by area, 1970 and 1982

Area	Year	Number of respondents Unweighted	Weighted
Bob Marshall Wilderness	1970	125	—
	1982	396	310
Great Bear Wilderness	1970	78	—
	1982	166	111
Scapegoat Wilderness	1970	299	—
	1982	184	110
Bob Marshall complex	1970	502	—
	1982	[1]746	531

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[1] This total is less than the 785 questionnaires returned because of exclusion of 39 responses from visitors who were not within the specified sample population (nonrecreationists such as guides, trail crews, and researchers; underage visitors; persons not going beyond trailhead area such as berry pickers, etc.).

ANALYSIS

The analysis consists basically of cross tabulations of variables and comparisons for selected variables, particularly between 1970 and 1982. Comparisons between years and among areas usually are based on classification of visitors in terms of day-use or overnight visits, method of travel used, and either summer or fall use, or hunter or nonhunter visitors. (These last two classifications are very similar; only 1 percent of summer users hunted, while 75 percent of the fall visitors did.) Correlation analysis was used for a few relationships, especially for satisfaction and aspects of the trip experience. The results will be interpreted in terms of management implications.

Statistical confidence intervals have been calculated for most important factors for 1982. Because of the difficulty of calculating confidence intervals for complex, clustered samples, this was not done for all 1970 data. The 95 percent confidence interval—plus or minus two standard deviations—is shown in the tables. For data where confidence intervals are available for both 1970 and 1982, they appear to be approximately equal, with slightly larger confidence intervals for the 1970 data, primarily due to smaller sample size in 1970. This rough equality probably would also apply to other data where 1970 confidence intervals are unavailable. Readers can judge statistical significance for themselves. Differences greater than the sum of confidence intervals for the 2 years are clearly statistically significant; lesser differences involve some overlap of confidence intervals and the possibility that the difference reflects sampling variation.

Statistical tests such as chi-square generally have not been presented. With the large sample sizes, even small differences—too small to have substantive importance—are statistically significant, so there is nothing to be gained by such tests.

Group and Individual Frames of Reference

For all three areas in both years, data can be presented either for individuals (16 years of age or over) or for groups. This was achieved by tagging one randomly selected respondent from each group and using only those respondents for basic descriptive data that logically refer to the group. Examples include group size, route of travel, length of stay, and method of travel. Other variables, such as personal socioeconomic data, activities, and attitude, were tabulated on an individual basis. A few variables, such as length of stay, are worth looking at from both perspectives. In 1982, few groups had more than one person sampled (table 2). In 1970, however, multiple respondents from the same group were more common. Thus, fewer different groups were sampled, providing less data on group characteristics.

Table 2.—Distribution of sample among "party representatives"[1] and other members of the party, percentage of total, Bob Marshall complex, 1970 and 1982

Year	"Party representatives"	Other party members
1970	50	50
1982	74	26

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[1] "Party representatives" consisted of one respondent per group. For groups with more than one respondent, this was the person whose questionnaire was logged in first.

USE CHARACTERISTICS

Some recreation use characteristics shifted from 1970 to 1982, and others remained essentially unchanged. The pattern of shifts and stability described below for various use characteristics generally seems to present a moderate evolution, and to form a logical pattern, which appears consistent with probable general trends in wilderness recreation.

Method of Travel

The proportion of visitors to the complex who were hiking rather than using horses grew from 1970 to 1982 (table 3). In 1970, horse users were in a clear majority, but by 1982 the proportions were reversed, and hikers predominated. This is the most basic change in the characteristics of use, and shows up in many other characteristics (fig. 3). Horse users were less often hiking with packstock and more often riding in 1982. The proportion of visitors running rivers was 3 percent for both years.

In the Bob Marshall Wilderness, horse users went from outnumbering hikers better than two to one in 1970 to an even split in 1982. Horse use may have been much more dominant in earlier years; in 1959 it was estimated that more than 90 percent of Bob Marshall visitors were on horseback (ORRRC 1962).

Total horse use in the complex has grown, but not as rapidly as hiking, and thus it is a smaller proportion of the total. If total use has increased about 60 percent from 1970 to 1982, as official use estimates suggest, horse use grew about 20 percent, but hiking use grew almost 130 percent.

Hunters were predominantly horse users both years; in 1982, 69 percent of hunters used horses in the complex, compared to only 32 percent of nonhunters. For 1970, the corresponding percentages were 79 and 42.

The proportion of campers using horses in both years was much higher than for day-users; in 1982, 45 percent of campers used horses, but only 15 percent of day-users did; in 1970 the corresponding figures were 61 and 31 percent.

The average horseback party in 1982 had a little over nine animals, down from more than 12 in 1970, and the average party of hikers with packstock had five head, up slightly from 1970. The decline in number of horses per party appears to be about equal to the increase in numbers of parties with horses, so the total number of horses is probably not much different between the 2 years. The shorter stays described in the next section could mean that total horse-days of use were less in 1982 than in 1970.

Relatively faster growth of backpacking than horse travel has been common speculation nationwide; the trend has now been documented for the Bob Marshall complex. Although total use has grown, the shift toward more hiking, together with the trend to smaller parties, described below, should offer at least the potential for reduced impacts to campsites and erosion of trails.

Table 3.—Method of travel in the Bob Marshall complex, 1970 and 1982

	Percentage of total individual visits				
Year	Hike	Horseback	Hike with packstock	Raft	Other
1970	40	49	6	3	2
1982	[1] 57 ± 7	36 ± 7	3 ± 1	3 ± 2	1 ± 1

[1] Statistical confidence interval at the 95 percent level. There is a 95 percent probability that the true value would fall within the interval indicated.

Figure 3.—By 1982, backpackers had surpassed horse users as the majority of visitors.

Length of Stay

Visitors' average lengths of stay were shorter in 1982 than in 1970, down to 4.7 days from 5.1 (table 4). Day-users were about the same proportion of visits in 1982 as in 1970, 22 percent compared to 20 percent, and the proportion of short trips (2 to 4 days) was also little changed. More 1982 visits were about 1 week long (5- to 7-day trips) but fewer were in the 1- to 2-week range compared to 1970.

In both years, the Bob Marshall Wilderness had the longest average stays, between 5½ and 6 days. In 1970 the Scapegoat Wilderness had the shortest average stay, about 3 days. In 1982 the Great Bear Wilderness had the lowest average length of stay, a little more than 3 days.

Horseback travelers in 1982 averaged stays about 1.75 times as long as hikers, 6.3 days compared to 3.6. In 1970 the differences were greater; horseback travelers averaged 7.4 days, and hikers only 2.9, a 2.5:1 ratio. This lower average stay by hikers reflects the much higher proportion of day-users among hikers in 1982, 32 percent, than among horseback riders, only 8 percent. If only campers are compared, the difference in 1982 between backpackers and horseback travelers narrows, with average stays of 4.8 days for backpackers compared to 6.7 days for riders.

Hunters in 1982 stayed longer, on the average, than nonhunters, 6.7 days compared to 4.3. If day-users are excluded, the average stays for campers are 7.4 days for

Table 4.—Length of stay in the Bob Marshall complex, 1970 and 1982

		Percentage of individual visits for each number of days									
Year	Average stay, days	1	2	3	4	5	6	7	8-10	11-14	15+
1970	[1]5.1 ± 0.6	20	11	13	11	4	5	6	19	10	1
1982	4.7 ± 0.5	22	9	15	9	8	8	10	13	5	1

[1] Statistical confidence interval at the 95 percent level. There is a 95 percent probability that the true value would fall within the interval indicated.

hunters and 5.3 for nonhunters. These average stays were almost identical in 1970.

One of the reasons average lengths of stay declined from 1970 is the shift toward relatively more hiker visits with their shorter stays and toward relatively fewer horseback visits, and fewer hunters.

Party Size

In 1982 the Bob Marshall Wilderness had the largest average party size, 4.7 persons, unchanged from 1970 (table 5). From 1970 to 1982, average party size in the Great Bear Wilderness dropped to 3.8 from 5.2 and in the Scapegoat Wilderness to 4.4 from 5.6. Parties larger than 20 disappeared in 1982, as intended by a regulation that went into effect in all three areas in June 1982, setting 15 persons as the maximum permissible party size. Nevertheless, total compliance was not achieved in 1982; in the three-wilderness complex, 2 percent of all sampled parties had 16 to 20 members.

Parties visiting the complex using horses averaged larger than hikers both years. The parties larger than the 15-person maximum were twice as likely to be horse travelers as hikers in 1982, but not in 1970. River floating parties also tended to be large, and had the highest percentage of parties over the maximum permitted size in 1982.

Larger parties in both years were much more likely to be campers than day-users. All of the persons sampled from parties with more than 15 people were campers, and most of the parties with more than 10 members were also campers. The proportion of large parties in 1982 was identical when hunters and nonhunters were compared, for both the 11- to 15- and the 16- to 20-person categories, but in 1970 the very large parties were much more likely to be nonhunters.

Smaller party sizes in 1982 and the absence of very large parties are desirable from a management standpoint, as suggested by the regulation limiting party size. Larger parties are believed to have disproportionately adverse effects on both other parties' experiences (Stankey 1973) and probably also on at least some aspects of biophysical resources (Cole 1981).

Outfitter Use

The declining trend in the proportion of visitors traveling with outfitters parallels the decline for horse travel (table 6). Outfitter use in both study years is concentrated in the fall, associated with hunting. In 1970 all outfitted parties traveled with horses, and almost all (96 percent) did in 1982 also (fig. 4). In 1982, however, some visitors used the services of river float outfitters (16 percent of all visitors floating). Another 10 percent of all floaters used horse outfitters to reach their launching point. A few backpackers (3 percent) also used horse outfitters' services for some portion of their trip. Hunters used outfitters more than twice as much as nonhunters both years; in 1982, 31 percent compared to 14 percent; in 1970, 47 percent compared to 20 percent. More than 80 percent of 1982 Bob Marshall complex visitors traveled without outfitters, and about 64 percent of the visitors on horseback were not with outfitters. If a 60 percent increase in total use from 1970 to 1982 again is assumed, it appears the total number of outfitter guests is about the same or slightly down

Table 6.—Outfitter use in the Bob Marshall complex, 1970 and 1982

	Percentage of total visits with outfitter			Percentage of total visits for each type of service	
Year	Total	Summer	Fall	Fully outfitted	Spot packed
1970	31	21	46	28	3
1982	17 ± 4	14 ± 4	24 ± 5	15 ± 4	2 ± 1

Table 5.—Party size by area, 1970 and 1982

			Percentage of total parties with indicated number of people						
Area	Year	Average number of people per party	1	2-4	5-7	8-10	11-15	16-20	21+
Bob Marshall	1970	4.7 ± 1.0	6	50	36	6	0	0	2
Wilderness	1982	4.7 ± 0.5	6	61	15	10	5	3	0
Great Bear	1970	5.2 ± 1.1	0	66	7	20	7	0	0
Wilderness	1982	3.8 ± 0.5	5	72	15	7	1	0	0
Scapegoat	1970	5.6 ± 1.3	6	60	18	2	5	4	5
Wilderness	1982	4.4 ± 0.7	11	60	14	9	2	4	0
Bob Marshall	1970	4.9 ± 0.7	5	54	28	8	2	1	2
complex	1982	4.3 ± 0.5	8	63	14	9	4	2	0

Figure 4.—Almost all visitors traveling with outfitters used horses.

over this period. During much of this time, no new outfitter permits were issued, so this lack of growth may be close to the actual situation.

Activities

From 1970 to 1982, the proportions of visitors engaged in most of the activities in the complex showed little or no change, and the average number of reported activities remained nearly the same for both years in each area and for the complex (table 7). Fishing (fig. 5), hiking, and photography are the three major activities, the only ones generally participated in by over half of the visitors. All but fishing grew in popularity from 1970 to 1982. Fishing participation dropped slightly. Hunting was the only activity with a substantial decline in participation rates from 1970 to 1982.

Swimming, a minor activity, increased in participation rates. Nature study stayed moderately high, increasing slightly. Mountain climbing was very rare everywhere both years.

In general, there appears to be a slight shift from the more consumptive uses (hunting and fishing) to the more contemplative activities (photography, nature study, hiking).

Figure 5.—More than half of the visitors fished in both 1970 and 1982.

Fire and Stove Use

Campfires and wood gathering for fires can create substantial impacts (Cole and Dalle-Molle 1982). Total reliance on wood fires dropped from 1970 to 1982 (table 8). The proportion of visitors who had a gas stove, either alone or in combination with wood fires (usually cooking on the stove and using the wood fire for warming or for its charm), almost doubled (fig. 6).

Some of the visitors in 1970 who reported no campfire or gas stove probably used wood stoves, typically in a wall tent, often at an outfitter's camp, rather than doing without any source of heat. If the 1982 figure for wood stoves (the last column in table 8), and no fire or stove at

Table 7.—Activities participated in, Bob Marshall complex, 1970 and 1982

Year	Percentage of total visits involving activity								Average number of activities
	Fish	Hunt	Hike	Photography	Nature study	Mountain climb	Swim	Other[1]	
1970	61 ± 8	[2]32	60	56	26	0.3	11	17	2.7
1982	57 ± 7	16 ± 7	68 ± 5	61 ± 5	28 ± 5	.8 ± 1	17 ± 4	15 ± 3	2.6 ± 0.1

[1] "Other" was made up mainly of rafting and of people flying to the Schafer air field in the Great Bear Wilderness who had no appreciable ground travel.

[2] Confidence intervals not available for any activities in 1970 except fishing.

Figure 6.—A smaller proportion of visitors cooked over campfires in 1982 than in 1970, and more used petroleum-fueled stoves.

all (the first data column), are combined, they are very similar to the 1970 "no fire or gas stove" data. Backpackers used stoves more and depended on wood fires less than horse travelers both years.

The most recent figures reemphasize a point made in reference to the 1970 data (Lucas 1980) and stressed by Hammitt (1982) that a campfire has strong appeal as a symbol of a traditional camping experience, even to campers who cook on a stove. Over 80 percent of the visitors using stoves also had campfires in both years (in 1982, 44 percent of all campers had a gas stove, but 37 percent of the total had a wood fire in addition to the gas stove, at least sometime, or 84 percent of those with stoves).

Banning all campfires would require major changes in visitor behavior. Minimum impact camping education, however, could stress ways of building small, "symbolic" fires. Such fires could have little impact, potentially less than cooking fires because they can be smaller, can burn more irregular down wood, consume less wood, and can sometimes more easily or conveniently be located on a resistant site than a cooking fire, which often has more limiting requirements for placement. Hammitt (1982) suggests that a small lantern might be a substitute for esthetic fires, and points out a number of ways to reduce campfire impacts short of a total ban.

These trends suggest the potential for some reduction in campfire impacts at campsites, a favorable change.

Wildlife Observation

Most visitors highly value the observation of wildlife in wilderness. This includes hunters and nonhunters. The wilderness setting probably enhances most observations of wildlife, and wildlife populations and behavior are relatively natural and unmodified.

Visitors were generally successful in observing major wildlife (table 9). The questionnaire listed the seven species in the table (plus an additional category—"bear, not sure which kind"), and asked if the visitor had seen each. Most species were observed by about the same proportion of visitors in both years. Elk, probably the species of greatest interest to most visitors, were the main important exception (fig. 7). Elk were observed by a smaller proportion of visitors in 1982 compared to 1970. More than half of the elk hunters, however, saw elk in 1982, a slightly higher percentage than 1970 (table 10). The percentage of hunters seeing deer also increased from 1970 to 1982.

In 1982, nonhunters more often saw grizzly bears, moose, and bighorn sheep than did hunters, about the same number of mountain goats, somewhat fewer deer (61 percent of nonhunters reported seeing deer, compared to 74 percent of hunters). They saw half as many black bears and only about one-third as many elk as hunters (17 percent of nonhunters saw elk versus 51 percent of hunters). In 1970, more nonhunters saw moose and sheep, about as many saw deer and goats, but fewer saw bears and elk.

Hunting

Elk hunting is a traditional activity in all three wildernesses, with deer hunting a secondary quarry for most hunters. Elk hunting success declined from 24 to 18 percent from 1970 to 1982 (table 10). Hunting regulations were more restrictive in 1982 than in 1970; during the early part of the 1982 season only antlered bulls could be taken, while both bulls and cows were legal in 1970. The percentage of hunters taking an elk was almost identical in all three areas in 1982.

Deer were seen more often than elk, but the proportion of hunters taking deer was not greatly different than for elk—higher in 1970 than 1982 (table 10). This is almost surely a reflection of most hunters' preoccupation with elk, which probably caused many of them to pass up shots at deer.

The sample of hunters of other species—bears, goats, sheep, and moose—was too small to analyze.

Table 8.—Use of wood fires and gas camp stoves in the Bob Marshall complex, 1970 and 1982

	Percentage of total campers[1]					
Year	No fire or stove	Wood fire only	Wood stove (in tent)	Gas stove only	Both fire and gas stove	Had a gas stove
1970	4	73	Not asked	4	19	23
1982	1 ± 1	51 ± 6	3 ± 1	7 ± 2	37 ± 5	44 ± 6

[1] Day-users excluded.

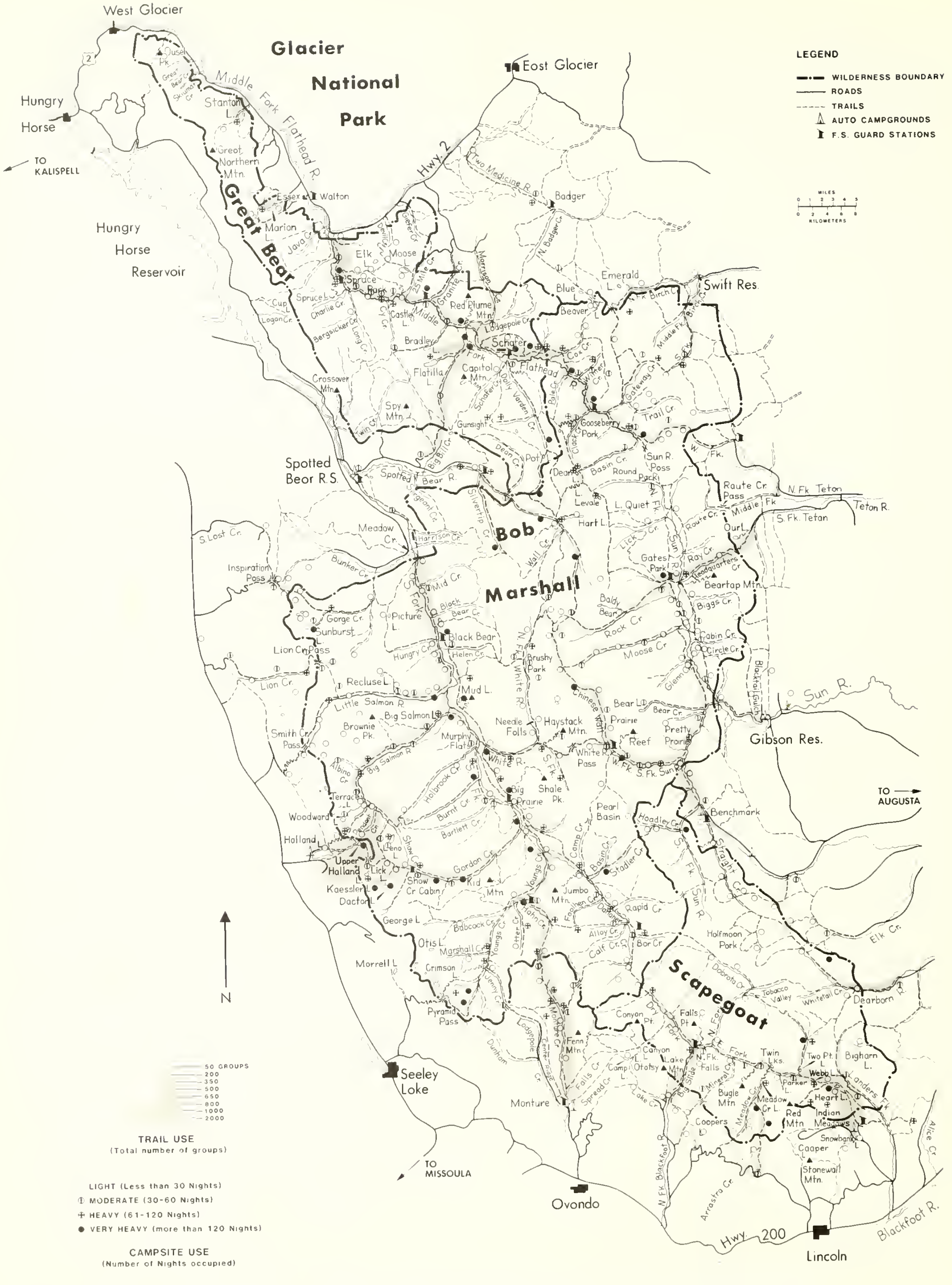

Figure 7.—The distribution of recreational use of trails, off-trail travel, and campsites in the Bob Marshall Wilderness complex, summer and fall, 1982.

Table 9.—Wildlife observation in the Bob Marshall complex, 1970 and 1982

	Percentage of visits on which respondents reported seeing:								
Year	Any major wildlife	Grizzly bear	Black bear	Bear, species unknown	Elk	Deer	Mountain goat	Bighorn sheep	Moose
1970	83	1	12	3	36	64	9	4	11
1982	70 ± 7	3 ± 2	8 ± 2	1 ± 1	23 ± 6	63 ± 8	13 ± 4	4 ± 2	6 ± 5

Table 10.—Hunter observation and success for deer and elk, by area, 1970 and 1982

		Percentage of total hunter visits			
		Elk		Deer	
Area	Year	Saw	Got	Saw	Got
Bob Marshall Wilderness	1970	46	25	40	40
	1982	51	18	74	7
Great Bear Wilderness	1970	74	41	80	13
	1982	36	18	74	18
Scapegoat Wilderness	1970	27	5	83	25
	1982	57	16	73	22
Bob Marshall complex	1970	48	24	54	33
	1982	51	18 ± 1	74	14 ± 1

Table 11.—Time of entry in the Bob Marshall complex, by season, weekday or weekend, and month

	Percentage of total visits									
Year	Summer	Fall	Weekday	Weekend and holiday	June	July	Aug.	Sept.	Oct.	Nov.
1970	66	34	31	69	3	44	16	17	18	2
1982	80 ± 8	20 ± 8	42 ± 11	58 ± 11	3	39	35	15	9	—[1]

[1] November was not sampled in 1982.

Timing of Use

Summer is the main season of use in the three-wilderness complex in both 1970 and 1982 (table 11), and in each individual area. The concentration of use in the summer increased from 1970 to 1982.

Use on weekdays, defined as Monday through Thursday, was lighter than on weekends, defined as Friday through Sunday, plus Independence Day and Labor Day (table 11). The weekend rush was less pronounced in 1982 than in 1970.

July had the most use in both years. The 1982 sample indicates more August use than in 1970, and less October use. The other months were similar in both years. The monthly use figures need to be treated as general indications because of the effects caused by random selection of sampling points—some popular places being sampled on busy days in one month, with other sampling dates falling on lightly used places or times in another month.

USE DISTRIBUTION

Wilderness recreational use typically is distributed very unevenly among different wildernesses, among trailheads in a wilderness, and over the trail system and campsites of a wilderness (Lucas 1980; Stankey and others 1976). Uneven use distribution has implications for resource impacts, visitor solitude or congestion, trail maintenance, and visitor informational contacts.

Entry Point Use

All three of the wildernesses have concentrated use at a few popular trailheads (table 12). Each area's most used trailhead accounts for more than one-third of all 1982 visits, and the top two account for about half or more. In both years, and in all three areas, the most used half of the trailheads receive about 90 to 100 percent of all estimated visits.

Table 12.—Cumulative percentage of total use accounted for by varying number of entry points, ranked from most to least used, by area, 1970 and 1982

Entry points, ranked by number of visits	Bob Marshall Wilderness 1970	Bob Marshall Wilderness 1982	Great Bear Wilderness 1970	Great Bear Wilderness 1982	Scapegoat Wilderness 1970	Scapegoat Wilderness 1982	Bob Marshall complex 1982
1	45	34	85	32	68	40	11
2	62	48	92	47	78	53	20
3	75	57	100	60	85	64	29
4	83	64	100	68	91	73	35
5	89	70	100	74	95	80	40
6	93	75	100	81	100	86	46
7	95	79	100	86	100	91	50
8	97	84	100	90	100	95	55
9	98	88	100	94	100	98	58
10	100	91	100	96	100	100	62
11	100	93	100	98	100	100	65
12	100	95		99	100		67
13	100	97		99			70
14	100	98		100			72
15	100	99		100			74
16	100	100		100			76
17		100		100			78
18		100					80
19		100					82
20							83
21							85
22							86
23							88
24							89
25							90
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27							92
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31							96
32							97
33							97
34							98
35							98
36							99
37							99
38							99
39							99
40							100
41							100
42							100
43							100
44							100
45							100
46							100
47							100
48							100
Total sampled	16	19	11	18	12	11	48

The 1982 data for the entire wilderness complex, for all 48 trailheads where use was sampled, show that just the seven most used trailheads had half of all use (table 12). The most used half had about 90 percent of total visits.

Trailhead use was less concentrated in 1982 than in 1970 in each area, and particularly in the Great Bear Wilderness. I believe use has dispersed, partly as a result of visitor attempts to avoid heavily used areas, probably particularly by the summer backpackers who are now more common. In the Great Bear, the extreme concentration at the Schafer air field has decreased, apparently as visitor awareness of other access points has grown. Some of the Great Bear trailheads with relatively more use in 1982 are reached by logging roads that had been built only a few years before the 1970 survey and may not have been widely known. There has not been any specific information effort to encourage visitors to disperse.

As for monthly use patterns, trailhead use should be compared with caution. The sample is fairly small even at popular trailheads and very small at lightly used ones. Estimates of total use are subject to large variation due to random chance; for example, the trailheads sampled the few days before the hunting season opened were busy, whereas those sampled a week earlier were usually quiet. Weather at sampling time influenced use at specific trailheads. The sample was designed to estimate accurately the overall characteristics of use and users, but, inevitably, not total amounts of use or distribution in great detail.

Routes of Travel and Trail Use

The uneven use of trailheads results in uneven use of trails. In fact, trail use is more uneven than trailhead use because of variation in the distances visitors travel and uneven choice of alternate routes at trail junctions. Figure 7 presents the pattern of visitor flows over the Bob Marshall complex in 1982.

Use is heaviest east of Holland Lake, but also heavy on a number of other trail segments including: from Holland Lake over the Swan Range and down both Gordon and Big Salmon Creeks; from the Meadow Creek trailhead south up the South Fork of the Flathead; to Stanton Lake; south up the Middle Fork; around the Schafer air field (east, west, south, and to Flotilla Lake); from the South Fork of the Teton River over Headquarters Pass to Gates Park; from Benchmark down the South Fork of the Sun River and up its West Fork; from Indian Meadows to Heart and Webb Lakes; and north up Monture Creek over Hahn Pass and down to Youngs Creek. Many other trail segments had only light use, and some, even with data from almost 750 parties, had no sampled use. The most lightly used areas are often not the most remote, and some remote areas, for example, around Big Prairie, are heavily used.

Because of small samples, use was not mapped for the Bob Marshall or Great Bear Wilderness in 1970. The overall pattern in the Scapegoat Wilderness was quite similar in 1970 (fig. 8) and 1982 (fig. 7).

Only a few of the sampled parties did not actually cross the wilderness boundary, although in many places the boundary is distant from trailheads. Entering the wilderness were 98 percent in the Great Bear, 92 percent in the Bob Marshall, and 91 percent in the Scapegoat Wilderness. Thus, the study results represent use of the legally defined wilderness well, even though visitors to the undeveloped peripheral wildlands were not excluded from the sample.

For the three-wilderness complex, there were only modest changes in the frequency distribution of distance traveled per trip (table 13). In 1982 there were more very short trips (not over 5 miles [8 km]) and, at the other extreme, very long trips (over 50 miles [83 km]) than in 1970. Most of the increase in very long trips occurred in the Bob Marshall Wilderness, and most of the increase in very short trips was in the Great Bear Wilderness. The pattern of trip length in the Scapegoat Wilderness was very similar in both years.

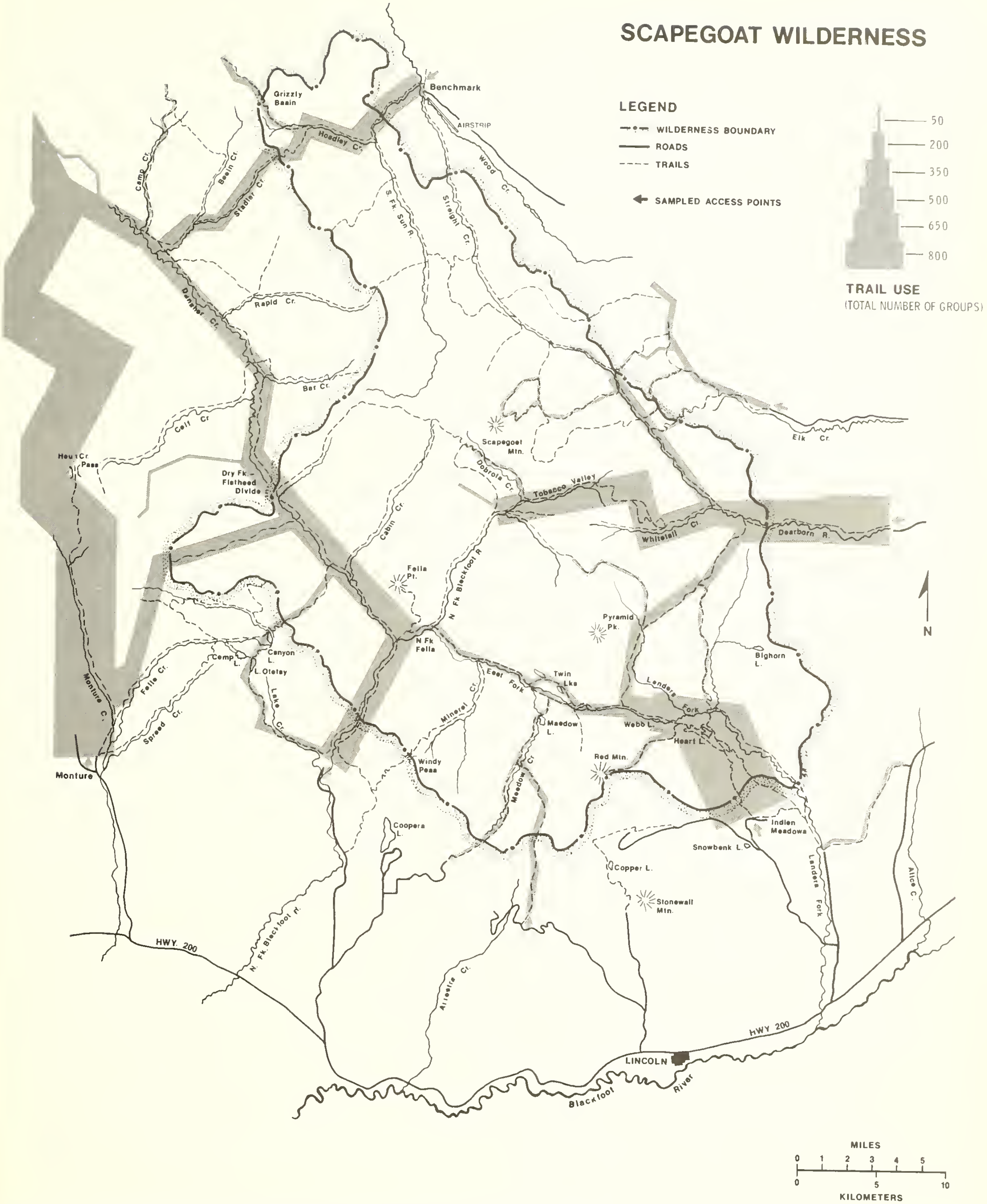


Figure 8.—The distribution of recreational use of trails in the Scapegoat Wilderness, summer and fall, 1970.

Table 13.—Total distance traveled beyond roads in the Bob Marshall complex, 1970 and 1982

Year	Average distance traveled, miles, round trip	Percentage of total groups traveling indicated number of miles, round trip: 5 or less	6-10	11-20	21-30	31-50	51 or more
1970	28	3	17	29	15	22	14
1982	30±4	7	11	25	20	17	20

Unlike many wildernesses studied elsewhere (Lucas 1980), most trips in the Bob Marshall complex are fairly long, averaging about 30 miles (48 km) both years (table 13). Problems of congestion and impacts are probably not as concentrated in the periphery of the Bob Marshall complex as is the case in many other areas.

Off-trail travel is rare in the Bob Marshall, much of which is steep and heavily forested. Only 10 percent of the visitors showed any off-trail travel on the maps of their routes in both years. About half of those who did indicate off-trail travel covered 5 miles (8 km) or less cross-country. There was little difference among various methods of travel.

This suggests that trails in this wilderness are a powerful management tool; they largely control where visitors go, what they see, and where most impacts will occur.

Campsite Use

Campsite use is also concentrated. Many campsites in figure 7 were estimated to be occupied less than 30 nights in 1982 (the "light" category), but a number were estimated to be used over 120 nights (the "very heavy" category), or almost constantly. Campsite use in 1970 was not analyzed in detail.

Readers should be particularly cautious of overinterpreting campsite use data on the map for two reasons. First, the data are based on information supplied by visitors who indicated on questionnaire maps where they camped and how long. Because campsites could not be located precisely on the small-scale maps, some locations are undoubtedly erroneous. Second, even if all visitor-supplied data were exact, samples for individual campsites are small—in effect, the sample is stretched thin—and therefore subject to large variances.

Consistent with the relatively long trips in the Bob Marshall complex, many parties camp at a number of different sites on a trip. In 1982, about 46 percent of all campers used only one campsite, but 20 percent used two, 13 percent used three, 6 percent used four, and 15 percent used five or more different campsites. In 1970, campers used fewer sites; 70 percent used only one, 13 percent used two, and 12 percent used three to five. The trend toward use of more campsites is another reflection of the shift toward more backpacker use because backpackers used more campsites than horseback travelers both years. Hunters were more likely to operate from one base camp; in 1982, 78 percent of the hunters used only one campsite, 14 percent used two sites, 8 percent used three to five campsites, and none used over five.

This use pattern suggests that most campsites are usually not used for extended periods of time, except in the fall, and then usually by visitors with horses, with the resulting potential for concentrated, cumulative impacts.

Summary of Use Characteristics

From 1970 to 1982, the Bob Marshall complex experienced a major change in use: backpackers began to outnumber horse users. The traditional style of travel, saddle horses and a pack string, is no longer the majority. Most other changes seem to stem from this basic shift: shorter stays, smaller parties, a smaller proportion with outfitters, some shift in activities from more consumptive to more contemplative, more summer use and less fall use, more moving from one campsite to another.

Other changes are less obviously related to the growth of backpacking: weekend peaking down, use less concentrated at access points, and less dependence on wood campfires. Wilderness managers will find this good news because most of these changes mitigate the impacts of growing use—probably up at least 60 percent from 1970 to 1982. The potential for impact from the average party should be less in the 1980's than in 1970, even if visitors' level of concern and skill were assumed to be unchanged.

VISITOR CHARACTERISTICS

Residence

Visitors to the Bob Marshall Wilderness complex come from all regions of the United States and even foreign nations, but more than 60 percent are from Montana (table 14). About 54 percent of the 1982 visitors are from northwestern Montana (fig. 9)—the areas closest to the wilderness. The 1970 figure was 57 percent from the same area. From 1970 to 1982, however, the proportion of visitors from outside Montana increased, especially from the central plains, eastern Lake States, and the Northeast, whose share grew from 8 to 15 percent.

In 1982 the Bob Marshall Wilderness drew the most out-of-State visitors, 43 percent, while the Great Bear and Scapegoat Wildernesses each had about 37 percent out-of-State visitors. This suggests that the Bob Marshall Wilderness is better known nationally than the two relatively new wildernesses.

Table 14.—Area of residence for visitors, Bob Marshall complex, 1970 and 1982

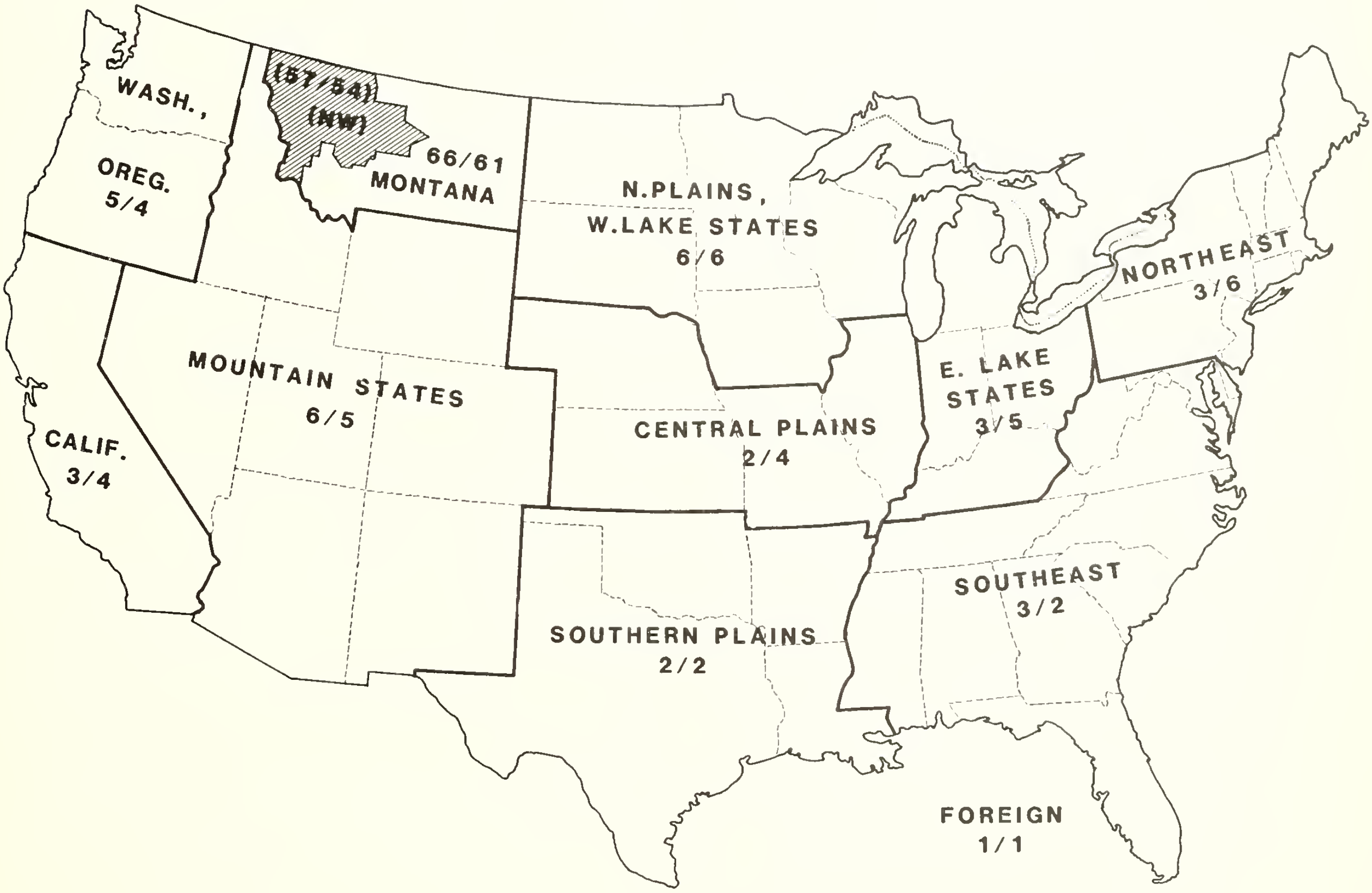
Visitor residence[1]	Percentage of total visits	
	1970	1982
Montana	66	61 ± 4
Mountain States (except Montana)	6	5
California	3	4
Washington, Oregon	5	4
Northern Plains, western Lake States	6	6
Central Plains	2	4
Southern Plains	2	2
Eastern Lake States	3	5
Southeast	3	2
Northeast	3	6
Foreign	1	1

[1] See figure 9 for definitions of visitor residence regions.

The Scapegoat Wilderness showed the most pronounced shift in visitor origins from 1970 to 1982, going from an overwhelmingly local clientele (86 percent from Montana) in 1970 to a much more national visitation pattern in 1982 (62 percent from Montana, 38 percent from outside the State). The proportion of visitors to the Scapegoat Wilderness from about every region of the country outside Montana grew from 1970 to 1982.

The percentage of hikers and of horse travelers from out of State in 1982 was almost identical (about 40 percent of the total in each case). Rafters were less often from out of State (27 percent of all rafters). These represent shifts from 1970, when horse users were more likely to be from out of State than hikers (41 vs. 30 percent), and when no sampled rafters were from outside Montana. Apparently national awareness of the Bob Marshall complex as a place to visit to backpack or float rivers has grown over time.

Hunters were slightly more often from out of State than nonhunters in 1982—42 percent of hunters compared to 39



KEY : 6/5 PERCENT OF TOTAL VISITORS, 1970/'82

Figure 9.—Most visitors to the Bob Marshall Wilderness complex both years lived in Montana, mostly in northwestern Montana, but the proportion coming from outside Montana, especially the northeastern quarter of the Nation, increased from 1970 to 1982.

percent of nonhunters. Campers in 1982 were also more often from out of State than day-users—42 percent of campers compared to 29 percent of day-users. Here also there are shifts from 1970, when hunters were substantially more often from outside Montana than were nonhunters (42 vs. 29 percent), and campers over twice as likely to be from out of Montana as day-users (34 vs. 16 percent). It seems that in 1970 the Bob Marshall complex had acquired considerable national publicity as a place for a wilderness hunting trip, traveling with horses, but was not well known for other types of wilderness experiences, except locally. This changed by 1982, as the area became more widely appreciated for a variety of forms of recreation.

Information programs conducted in Montana can potentially reach about 60 percent of all visitors to the Bob Marshall Wilderness complex. A substantial proportion of the 40 percent who live elsewhere travel with outfitters who can be an important channel for information on wilderness values and appropriate behavior. Other out-of-State visitors will be more difficult to contact. A diverse educational effort seems necessary. Some general wilderness education needs to be conducted nationally. Contacts with ranger stations and supervisors' offices need to be recognized as very valuable and should be used fully, and some contact on the ground, at trailheads or in the wilderness, can supplement other approaches.

Over 70 percent of the day-users were from Montana, which may imply either a need for more local opportunities for short day hikes or rides outside wilderness, or for more information to increase local residents' awareness of such opportunities.

Urban/Rural Residence

Most of the visitors to the Bob Marshall Wilderness complex are from small- to medium-sized urban areas—in 1982 about 60 percent were from urban areas, but only 8 percent were from large cities (over 1 million people). This is little different from 1970, when 65 percent were from urban areas, and only 5 percent from large cities. This reflects the fact that most visitors were from Montana, which has no large cities.

The pattern of urban/rural residence for different types of visitors was generally stable from 1970 to 1982. In both years, hikers and rafters were substantially more urban than horse users, and hunters were less urban than nonhunters. The only shift was for day-users compared to campers; in 1970, day-users were more urban than campers, but the reverse was true in 1982. The differences were not large either year.

Urban residents make up 51 percent of the Montana population, and 50 percent of the Montana visitors to the Bob Marshall complex were from urban areas, compared to 74 percent of the visitors from outside Montana, which is also equal to the 74 percent of total U.S. population which lives in urban areas. Thus there is little support in the data from either Montana or out-of-State visitors for the idea that wilderness visitors, at least to this wilderness, are disproportionately from urban areas, presumably seeking escape from urban conditions.

In 1970 the childhood residence ("most of the years before you were 18") of visitors was much more rural than their current residence—56 percent had grown up in rural and small-town surroundings, but only 35 percent still lived in such places. By 1982, however, the difference between childhood and current residence had narrowed; 47 percent had a rural childhood residence and 40 percent currently lived in rural areas.

Some people may be attracted to wilderness by the contrast between rural surroundings in childhood and the pressures of city living in adulthood (Lucas 1980). Wilderness visits may thus fulfill a longing for open spaces and contact with nature for people who have not entirely adapted to city living, so the notion runs. At an earlier stage in America's history, a major migration from rural to urban areas indeed took place. In 1970, there were 21 percent more visitors who had grown up in rural areas or small towns than who currently lived there—about twice the magnitude of the shift in the general population. This lends some support to the "nostalgia theory." In 1982, the difference was only 7 percent for visitors, but again about twice the shift for the general population.

Thus, there still is support for the theory in the 1982 figures, but its effect is weakening as fewer people experience rural-to-urban migration, and in the future its effect would likely disappear. This could lead to some slight dampening of the rate of growth of wilderness visitation.

The fact that most visitors are from urban areas, and that this is most true for the visitors not using horses, may contribute to less visitor understanding of horses and the practical problems faced by horse handlers, and less tolerance of horses' impacts.

Sex

Most visitors are males in both years, but the proportion of female visitors grew from 20 percent in 1970 to 30 percent in 1982. Women were fewer during the hunting season, but again 1982 was different than 1970, with 9 percent of all visitors being female compared to only 3 percent in 1970. There was little difference among different travel methods in the proportion of female visitors. A wider cross-section of society now benefits from wilderness than in 1970 (fig. 10). Education efforts need to be attuned to both men and women.

Types of Groups

The distribution of different types of social groups was almost identical between the two years. A majority of visitor groups consisted of families (including parts of families and families with friends) in both 1970 and 1982 (table 15). Groups of friends, without family ties, were the second most common type of visitor group, and, again, the percentage is almost unchanged between the 2 years. Groups sponsored by organizations such as Scouts, churches, the American Forestry Association, Sierra Club, or Backcountry Horsemen were only 2 or 3 percent of all groups both years. Solitary visitors were not common either year, making up 6 percent of the sample both years.

Figure 10.—Women increased from 20 percent to 30 percent of all visitors from 1970 to 1982.

The pattern of types varied with method of travel, length of stay (campers or day-use), and season of use. Almost all of the solitary visitors were hikers in both years, and most of the organization-sponsored groups were also hikers. The proportion of family groups and groups of friends was about the same for horse users, hikers, and other travel methods in 1982, but in 1970, horseback travelers were mainly groups of friends rather than families, much more so than hikers.

Day-users were more often family groups than were overnight campers both years, and more often alone. Campers were more often groups of friends and with organizations than were day-users.

Summer visitors were about twice as likely to be alone as fall visitors both years, and all organization groups visited in the summer both years. In 1982, groups of friends were somewhat more common in fall than in summer, but family groups were about the same in both seasons. In 1970, however, friends far outnumbered families in the fall, while families were more common than friends in the summer.

Thus, from 1970 to 1982, the predominance of family groups seems to have spread more uniformly across travel methods and seasons. This is consistent with the increased proportion of female visitors. This trend could suggest increased benefits through strengthened family ties.

Age

There was no appreciable shift in the distribution of various age groups from 1970 to 1982 (table 16). Almost half of the visitors in both years were 25 to 44 years old.

Age is often a contentious issue in debates about wilderness allocation. Some people express the idea that wilderness is inaccessible to older people (Norgard and others 1979). Table 16 show only modest underrepresentation of the 45 and older group among Bob Marshall complex visitors compared to the general population. The 25 to 44 age group is overrepresented; the 15 to 24 group is about equally represented in the wilderness and in the general population. The younger age group, 14 and under, is underrepresented, although the youngest children account for much of this underrepresentation.

The figures for the United States population in table 16 show an aging trend that could eventually have a negative effect on future growth in wilderness recreational use. Nevertheless, the short-run effect could be the opposite. In 1980 the proportion of the population in the 25 to 44 bracket increased, and this is the group from which the largest number of wilderness visitors come. This age group is projected to increase until about 1995 and then decline, while the 45 to 64 age group will increase greatly until it peaks about 2015, while the 10 to 24 age group remains fairly constant or declines slightly (Marcin and Lime 1977).

Table 16.—Age distribution, Bob Marshall complex, 1970 and 1982, and for the United States population, 1970 and 1980

Year	14 and under	15-24	25-44	45 and over
	Percentage of Total Visitors			
1970	11	17	48	24
1982	10	21	48	21
	Percentage of Total Population, United States			
1970	28	18	24	30
1982	22	18	29	31

Table 15.—Type of group, Bob Marshall complex, 1970 and 1982

Year	Type of group, as a percentage of total group visits: Family (all or part), with or without friends	Friends (unrelated)	Club or organization	Alone	Percentage of groups with children
1970	55	36	3	6	38
1982	55 ± 5	37 ± 5	2 ± 2	6 ± 2	NA

Education

Of all the social characteristics, the one that most distinguishes wilderness visitors is high education levels, and particularly high levels of study beyond college graduation. Education levels in 1982 were even higher than in 1970 (table 17). The contrast with national figures is striking. In 1982, 32 percent of the United States population went beyond high school. But 70 percent of the wilderness visitors not only went to college, 26 percent had postgraduate educations. Educational levels in Montana are slightly higher than for the Nation as a whole, but not enough to account for any appreciable portion of the high levels of visitor education.

In fact, the educational disparity between the general population and wilderness visitors is even greater than the figures in table 17 suggest. This is because census data on years of schooling are available only for persons 25 years or older, most of whom have completed their education. But the wilderness visitor data include some people as young as 16. About 20 percent of the sample respondents were under 25, and many were currently students, so that their current education level is usually lower than it would be when they were 25.

Education is generally the best socioeconomic determinant of leisure choices (Settle and others 1978), but the reasons for this extremely strong association of education and wilderness use are unstudied, to my knowledge. Several possible hypotheses come to mind. First, highly educated persons may gravitate to occupations with working conditions and stress that enhance the appeal of contrasting conditions in wilderness. Second, education may develop curiosity and interest about the natural world and hence interest in and enjoyment of wilderness. A third possibility is that curiosity and interest about nature may motivate people to seek more education, as well as wilderness recreation. Or, finally, the social influences of a university community may encourage wilderness recreation as part of life style, although this still leaves the unanswered question—why is wilderness recreation a prominent part of that life style? Perhaps all of these speculations have some truth.

In both study years, hikers had higher educational levels than visitors traveling with horses or rafting. In 1982, over half of the hikers were college graduates and almost one-third were or had been graduate students. Nonhunters had over twice as high a proportion of college graduates and graduate students as hunters in 1982, and day-user educational levels were slightly higher than for campers.

These findings are further confirmation of other studies (Lucas 1980; Hendee and others 1978). They stress again how unusually appropriate educational approaches could be in managing wilderness visitors. The audience of prospective wilderness visitors should be capable of understanding complex ideas, often should have knowledge of related topics, and should be skilled information processors. It also lends support to the idea, I think, that explanations of the reasons for recommended practices could increase acceptance and application in contrast to simple do's and don'ts.

Educational levels of the general population rose from 1970 to 1980, but it appears that future increases will be smaller, which might suggest a future slowing down in the rate of growth in wilderness use.

Occupations

Visitors in professional and technical occupations were the largest proportion both years (table 18). Professional and technical occupations (such as accountants, engineers, doctors, nurses, teachers, religious workers, and scientists) were even more common in 1982 than in 1970. Most other occupational groups were about equally represented both years, although students and homemakers were less common in 1982 than in 1970, and craftsmen, skilled and semiskilled workers, and laborers (blue-collar workers) were more common in 1982.

The drop in homemakers may be exaggerated because of sample selection. In both years individuals were sampled, not group leaders, but in 1970 the proportion of people in the same group who were sampled was higher than in 1982 (table 2). Thus, there was more opportunity for husbands to fill out the questionnaire, even though it was addressed to the wife, in 1982 than in 1970, when both husband and wife more frequently received questionnaires.

A number of occupations are overrepresented among visitors to the Bob Marshall complex compared to the

Table 17.—Education level distribution, Bob Marshall complex, 1970 and 1982; for the United States population and Montana, 1970 and 1980

Area	Year	0-8	9-11	12	13-15	16 or more[1]	(17 or more)[2]
		Percentage of total visits					
Bob Marshall complex	1970	4	13	24	18	41	(28)
	1982	2	7	22	23	47 ± 5	(26)
United States population[3]	1970	28	17	34	10	11	(NA)
	1980	17	14	37	15	17	(NA)
Montana population[3]	1970	25	16	34	14	11	(NA)
	1980	14	11	38	19	18	(NA)

[1] College graduates, usually.

[2] Graduate study, in most cases (also included in totals for "16 or more").

[3] Based on persons 25 years of age or older.

Table 18.—Occupational distribution, Bob Marshall complex, 1970 and 1982; and United States, 1970 and 1980

Occupation[1]	Percentage of total visits			
	Bob Marshall complex		United States population[2]	
	1970	1982	1970	1980
Professional and technical	32	37±4	8	9
Students	17	11	5	4
Homemakers	9	4	25	21
Craftsmen, operatives[3], and laborers	14	18	20	21
Clerical, sales, service	9	10	20	23
Business managers	9	8	6	7
Farm managers and workers	4	5	3	2
Military	3	2	2	1
All others, including retired and unemployed	3	5	11	12

[1] Based on the 1960 Census of Population Classified Index of Occupations and Industries (U.S. Department of Commerce, Bureau of the Census, 1960).

[2] Based on persons 16 years of age or older.

[3] Includes a variety of skilled and semiskilled occupations such as assembly line workers, butchers, gas station attendants, etc.

national population: professional and technical, about four times as common among visitors as among the general population, and students and farmers (table 18). Other occupations are underrepresented: homemakers, clerical, sales and service workers, and the retired, unemployed, and other category. In both years the proportion of professional and technical occupations and of students was higher for hikers than other visitors; 42 percent of hikers were in the professional and technical category in 1982. Businessmen, farmers, and blue-collar workers were more common among horseback travelers than hikers. Also in both years, fall visitors (three-fourths hunters) were less likely to be from the professional and technical professions or students, and much more likely to be blue-collar workers.

Previous Experience

How wilderness visitors behave, how much skill they have, how they evaluate their visit, and what they prefer are all shaped by their background experience. Most visitors to the Bob Marshall complex have visited some wilderness before—78 percent both years (table 19). In 1982, fewer (44 percent) visitors had previously visited the Bob Marshall complex than in 1970 (55 percent).

Most of the visitors with wilderness experience were introduced to wilderness while young. Both years close to 40 percent of the experienced visitors first visited wilderness before they were 16. About two-thirds had begun visiting wilderness by the time they were 25. About one-third were introduced to wilderness by their parents. The 1982 visitors were introduced to wilderness slightly younger than were 1970 visitors.

Both years visitors averaged three wilderness trips per year, and just under 10 total days annually in wilderness. This indicates a pattern of fairly frequent, fairly short trips, as well as considerable experience.

Table 19.—Wilderness experience, Bob Marshall complex, 1970 and 1982

Experience level	1970	1982
	Percentage of total visits	
Number of previous visits to Bob Marshall complex:		
0	45	56±5
1-2	18	16
3-5	17	14
6+	20	14
Previous visits to any wilderness	78	78±5
	------ *Averages* ------	
Number of wilderness visits in previous 12 months	3.0	3.0
Number of days in wilderness in previous 12 months	9.9	9.8
	Percentage of total visits by experienced visitors[1]	
Age at first wilderness visit:		
10 or less	18	19
11-15	19	20
16-25	28	31
26 and over	35	30
First wilderness trip with parents	35	33±5

[1] Includes only those with previous visits to any wilderness (78 percent of the total).

Hikers had more often visited some wilderness before than had horse users and river floaters both years. In 1970, hikers also more often had visited the Bob Marshall complex before, although the people with many previous visits—10, 20, even 50 or 60 visits—were more often horseback travelers. In 1982 this was reversed, however, and almost 60 percent of the backpackers were new to the Bob Marshall complex, compared to about 44 percent of the horseback travelers. Both years hikers tended to make more wilderness visits per year than other visitors, but, because the trips were shorter, they spent slightly fewer total days in wilderness over the previous 12 months than horse users. Hikers tended to be introduced to wilderness at a younger age than horse users or river floaters.

Hunters tended to have less general wilderness experience than nonhunters both years, but more experience with the Bob Marshall complex.

The lower level of visitor experience with the Bob Marshall complex itself in 1982 compared to 1970 is another indication of growing interest in the area, drawing more new visitors longer distances. The stability over 12 years in all of the other measures of experience is striking, and probably means that about the same sort of audience, in terms of experience, will face managers for many years.

The high level of experience needs to be considered in planning education efforts. Most visitors already have developed a certain wilderness behavior, right or wrong, and education usually is not starting with a clean slate. Changing bad habits is probably more difficult than starting fresh. On the other hand, the general familiarity with wilderness conditions might enhance education efforts. The early introduction to wilderness for many visitors may suggest that current wilderness education efforts directed at grade school or junior high school young people could be reaching prospective visitors at an opportune stage in their lives.

Information Sources

Use of education and information is an important wilderness visitor management tool and the major alternative to regulations. In 1982, visitors were asked if they had contacted the Forest Service for information in person, by telephone, or by writing; this question was not asked in 1970. Only 22 percent of the visitors had any contact with the managing agency (table 20). Only 13 percent had personal contact (fig. 11). Most visitors had maps both years, and these were usually Forest Service maps.

Horseback travelers and hunters both had less contact with the Forest Service than hikers, and were less likely to have Forest Service maps or any maps. This may be influenced by the higher level of experience in the Bob Marshall complex. Hikers were much more likely to have Geological Survey topographic maps than were other visitors.

The low level of agency contact is cause for concern. Efforts to increase contact seem to be needed, such as improving the amount and quality of available information to provide more incentive to the public for contacting the Forest Service, modified office hours to increase opportunities for visits by the public, and news stories to increase public awareness of information services available. Using maps to convey important information, for example, on minimum impact camping practices, seems worthwhile because maps are used by most visitors, although how much of such messages is read and their effectiveness is largely unstudied. Trailhead and backcountry contacts seem to be useful supplements to voluntary visitor contacts with the agency. Information in regional and national media also seems likely to reach some people missed by other techniques. Special efforts to reach hunters and horse users seem to be needed, especially because of their more limited contact with the agency and their potential for substantial impacts.

Figure 11.—Only 13 percent of the visitors had personal contact with Forest Service personnel in 1982.

Table 20.—Information sources used, Bob Marshall complex, 1970 and 1982

Year	Contacted Forest Service	Visited Forest Service office	Had any map	Had Forest Service map	Had other maps only	Had a guide-book
	Percentage of total visits					
1970	NA	NA	72	46	11	0
1982	22 ± 3	13 ± 3	63 ± 6	39 ± 5	14	2

Club Membership

A large majority of visitors to the Bob Marshall complex belong to no wilderness, conservation, or outdoor recreation clubs; in 1970, 69 percent did not; in 1982, 75 percent did not (table 21). Both years only 7 or 8 percent belonged to any wilderness-oriented club.

Both years horsemen were slightly more likely to be club members, with only minor differences in patterns of types of clubs, except that in 1982, horsemen were much more likely to belong to Backcountry Horsemen (which was organized after 1970) than were hikers (6 percent compared to less than 1 percent).

Hunters were less likely to belong to clubs in 1970, but had a slightly higher membership rate than nonhunters in 1982. Both years hunters were less likely to be members of wilderness organizations and more likely to belong to local recreation clubs such as rod and gun clubs.

Most club members belonged to only one club, but in 1982, hikers were more likely to belong to more than one club than horsemen. In 1970, the opposite was true.

Low club membership means that education efforts focused on clubs, although useful, only reach a small percentage of visitors and need to be supplemented with other educational approaches. This fact also lays to rest the notion that wilderness is mainly used by members of wilderness clubs.

Table 21.—Membership in wilderness-oriented conservation and outdoor recreation clubs, Bob Marshall complex, 1970 and 1982

	Percentage of total visits	
Membership	1970	1982
Number of clubs belonged to:		
0	69	75±3
1	18	15
2	7	6
3 or more	6	4
Wilderness-oriented clubs only[1]	4	4
Resource conservation clubs only[2]	8	5
Both wilderness and conservation clubs	4	3
Backcountry Horsemen	NA	3
Local outdoor recreation clubs	9	6
Combination other than wilderness and conservation	6	4

[1] Sierra Club, Wilderness Society, Friends of the Earth, American Wilderness Alliance, Montana Wilderness Association.

[2] American Forestry Association, Audubon Society, National Wildlife Federation, and similar organizations.

Summary of Visitor Characteristics

Many visitor characteristics remained about the same from 1970 to 1982. Those that changed did so only moderately. The essentially stable characteristics included urban/rural residence, social groupings, age, overall wilderness experience, and club memberships. Modest changes characterized area of residence (more visitors from out of State, especially from the central plains, north-central, and northeastern regions of the United States), sex (more female visitors), educational levels (higher), occupations (more professional or technical), and previous experience in the Bob Marshall (less). These changes seem to fit together consistently as expressions of increased visits by backpackers relative to other visitor types. Many of the user characteristics suggest slower future growth in visitation.

VISITOR ATTITUDES

Visitor attitudes alone do not determine wilderness management decisions, but they are important factors to consider in defining problems, setting standards for area conditions, and selecting management actions. Most use patterns and visitor characteristics described so far only changed moderately from 1970 to 1982, and many were almost unchanged. Have attitudes changed more, with implications for possible changes in management?

Attitude data will be presented and trends assessed for (1) general attitudes about the importance of wilderness and about wilderness appeals, (2) various aspects of carrying capacity issues, and (3) alternative management policies and actions.

General Attitudes

About three-fourths of all visitors both years said that wilderness was "extremely important" to them (table 22). Over 90 percent said wilderness was at least "very important." There is a slight tendency for 1982 visitors to report lower levels of personal importance. In both years day-users gave lower importance ratings than campers, probably because of less involvement with wilderness, at least on the sampled visit. Hunters also gave lower importance ratings both years, perhaps because for some of them the importance of the hunt itself tended to overshadow the wilderness aspects of the experience. Rafters also gave lower ratings, particularly in 1982, suggesting that the experience of floating a particular river may have been prominent compared to the wilderness setting—not unlike some hunters.

This high level of personal commitment to wilderness is part of the base for visitor education as a management tool, another advantage managers have in using educational approaches with wilderness visitors.

The appeals of wilderness, that is, the reasons people chose to visit a wilderness instead of some other type of recreational area, were approached differently in the two years. In 1970 the question was open ended, with no suggested answers (table 23). When asked this way, fishing emerged as the most often cited reason, with enjoyment of scenic beauty and hunting close behind, followed by experiencing solitude, escaping civilization, and avoiding mechanized recreation.

In 1982, respondents were asked to rate the importance of 10 appeals (table 23). Rankings of appeals varied from 1970, but how much of the variation is due to the different format of the question and how much to shifts over time cannot be determined. Nevertheless, the 1982 data present an interesting picture of the relative importance of different appeals. Enjoying scenic beauty

Table 22.—Importance of wilderness to visitors, Bob Marshall complex, 1970 and 1982

Year	Extremely important	Very important	Fairly important	Not very important	Not at all important
	Percentage of total visits				
1970	77	19	3	1	0
1982	73 ± 4	20 ± 3	6 ± 1	1 ± 1	0

Table 23.—Importance of various appeals of wilderness, Bob Marshall complex, 1970 and 1982

	1970		1982			
			Importance			
	Percent citing	Ranking	Very	Somewhat	Not	Ranking
	Percentage of total visits					
Experience solitude	15	4	49 ± 5	34	16	5
Avoid mechanized recreation	4	6	63 ± 5	23	14	4
Escape civilization	8	5	69 ± 4	24	7	3
Scenic beauty	20	2	85 ± 3	14	1	1
To fish	22	1	37 ± 6	35	28	6
To hunt	19	3	23 ± 6	11	66	10
To relax	1	7	70 ± 4	26	4	2
To exercise	—	10	29 ± 4	45	26	8
To develop skills	1	7	21 ± 4	47	33	9
Face challenge	1	7	32 ± 4	40	28	7

was ranked first by a wide margin. Relaxing, which barely was mentioned in 1970, was second, followed closely by escaping civilization and avoiding mechanized recreation. Experiencing solitude was fifth, and fishing dropped to sixth from first.

Recognizing the lack of full comparability between the 2 years, one could very cautiously speculate that there seems to be some shift from the consumptive, activity-oriented appeals (hunting and fishing) to more contemplative appeals (scenery, relaxation, escaping civilization). Of these, only escaping civilization seems to be substantially wilderness-dependent. Solitude and avoidance of mechanized recreation, two key characteristics of wilderness recreation in the Wilderness Act and thus clearly wilderness-dependent, are both moderately strong appeals in each year. Although the ratings of the personal importance of wilderness slipped slightly from 1970 to 1982, the personal definitions of wilderness in 1982, as reflected in ratings of various appeals, may be a bit more aligned with wilderness-dependent qualities.

Carrying Capacity

What has usually been called "carrying capacity" is a complex issue involving the effects of amount, type, timing and distribution of use, and of visitor behavior on both resources and on other visitors' experiences. Visitor attitudes toward and perceptions of these effects are vital to their interpretation. One approach to determining visitor attitudes is to consider levels of satisfaction and factors associated with it.

SATISFACTION

Visitors were asked "How well satisfied were you, personally, with this trip into the wilderness? What kind of a grade would you give it?" Available answers had both letter grades and adjectives, such as "A, very good," "B, good." Satisfaction levels overall were high both years, with 90 percent giving their experience an A or a B (table 24). There was almost no change from 1970 to 1982.

Satisfaction varied among certain types of visitors. Hunters expressed lower satisfaction in both 1970 and 1982 than nonhunters. In 1982, horsemen reported higher satisfaction than hikers, but in 1970 there was no difference. Campers expressed substantially higher satisfaction than day-users in 1982, but 1970 was slightly reversed. The lower satisfaction among hunters probably results from their preoccupation with hunting, as shown in their answers to questions about the importance of wilderness and wilderness appeal. Hunting success was not high, and this probably affected hunters' overall satisfaction. The difference that showed up in 1982 between horseback and hiking visitors and campers and day-users probably stems from differences in each type of users' expectations and standards. Results of questions about reasons for satisfaction and evaluation of certain conditions encountered which will be presented help clarify these differences.

After reporting their overall satisfaction, visitors were asked to identify specific satisfactions and dissatisfactions. The satisfying factors were similar in 1970 and

Table 24.—Overall satisfaction and major factors affecting it, 1970 and 1982

		Percentage of total visits	
		1970	1982
Satisfaction level	A	56	58±5
	B	34	32±4
	C	8	9±2
	D	1	1±1
	F	1	0
Factors affecting satisfaction	Environment and scenery	49	53
	Solitude, lack of crowding	12	17
	Crowding, conflict	7	20
	Good hunting, fishing	16	18
	Poor hunting, fishing	10	11
	Good trails, facilities	10	4
	Poor trails	2	12
	Litter	NA	5
	Wildlife observation	NA	9

1982. The major satisfying factor both years was the scenery and natural environment (table 24). The next two most common satisfying factors, in order, both years were good hunting and fishing, and solitude or lack of crowding. However, the pattern of dissatisfactions is different in 1982 and 1970. Crowding and visitor conflict were mentioned three times as often in 1982 as in 1970 (table 24), and complaints about poor trails were six times as common in 1982 (fig. 12). Clearly these two critical factors, solitude (which was mentioned more often in 1982 than in 1970, both as a source of satisfaction and as a source of dissatisfaction) and visitor impacts, at least to trails, were perceived as much more significant in 1982.

The major changes in attitude toward trail conditions and crowding probably resulted from changes in the visitor population (particularly more backpackers and more visitors making their first trip to the Bob Marshall complex) and changes in the conditions they experience. Nevertheless, overall satisfaction did not decline. This result is consistent with the two-factor theory of satisfaction (McCool 1984), which holds that satisfaction and dissatisfaction are two separate, independent factors, rather than two ends of a single continuum, and are not additive to produce an overall measure of satisfaction.

Different types of visitors varied little in terms of satisfactions. Hiker or horse user, day-user or camper, hunter or nonhunter cited about the same sorts of satisfactions both years. There are a few obvious exceptions for hunters compared to nonhunters; hunters cited hunting success and nonhunters did not, while fishing success was cited much more often by nonhunters. Dissatisfactions varied more. Visitors traveling by different means cited general crowding with about the same frequency (about 8 percent in 1982), but hikers complained much more about too many horse parties. Littering drew complaints from only about 5 percent in 1982, with hikers complaining a little more than horse users, but hikers mentioned horse manure as a dissatisfaction much more often than did horse travelers. Hikers also were somewhat more likely to cite poor trails as a source of dissatisfaction than were others in 1982 (14 percent compared to 10 percent for horseback riders). Hiker trail complaints stressed muddy conditions, which they often attributed to heavy horse use. Horsemen complained more about down trees, lack of brushing out, and lack of signs.

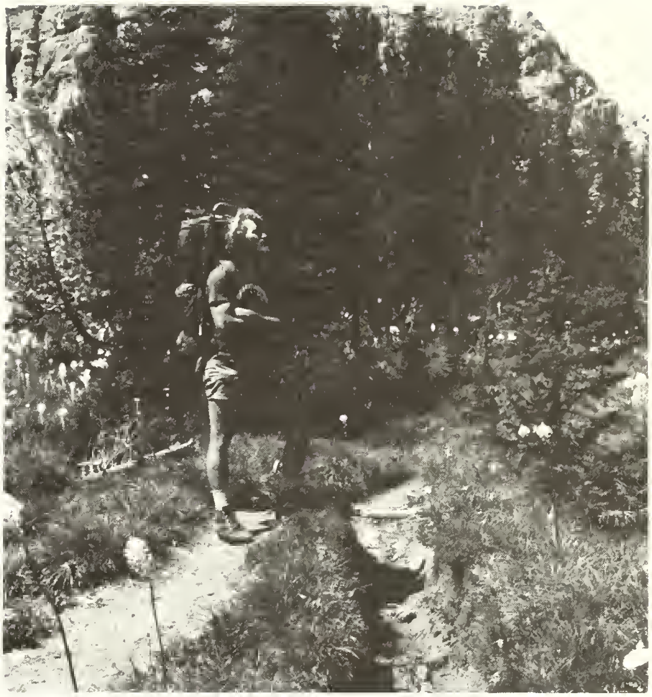


Figure 12.—Complaints about muddy and eroded trails were six times as common in 1982 as in 1970.

NUMBER OF PARTIES ENCOUNTERED AND VISITOR REACTIONS

Most visitors to the Bob Marshall Wilderness complex experienced low levels of encounters with other parties both years (table 25). The proportion meeting an average of one to two parties a day rather than none rose from 1970 to 1982, but the frequency of over two encounters per day was little changed. The overall average number of other parties met per day rose from 1.3 to 1.6 from 1970 to 1982. For campers the increase was from 1.0 to 1.2. This is substantially less than the assumed 60 percent increase in total use from 1970 to 1982, probably because of more evenly distributed use, and visitors' efforts to avoid one another.

There was almost no change in the pattern of opinions about the number met between the 2 years (table 25). Almost no one felt they met too few other visitors, most felt they met "about the right number," and about one-fourth both years felt they met too many others. Both years about 13 percent reported that numbers met did not matter to them.

This lack of change is consistent with the only slight increase in numbers of encounters both years. It does not seem obviously consistent, however, with the greatly

Table 25.—Average number of other parties met per day on the trip, distribution of average numbers met by each party, opinion of numbers met, and association of numbers met and opinion, Bob Marshall complex, 1970 and 1982

	1970			1982		
Type of visitor	All	Campers	Day-users	All	Campers	Day-users
Overall average	1.3	1.0	3.2	1.6 ± 0.3	1.2	3.0
	Percentage of total visitors					
Average numbers met per day:						
0	36	42	5	24	26	17
1-2	46	48	45	57	63	35
3-5	14	9	35	14	9	33
6-10	2	1	9	4	2	11
11-20	1	0	6	1	0	4
Over 20	0	0	0	0	0	0
Opinion of numbers met:						
Too few	2	2	1	2	1	3
About right	60	52	67	61	60	63
Too many	24	32	15	24	27	13
Didn't matter	14	12	17	13	11	20
Association of average numbers met per day and opinion of numbers met[1]	0.45	0.54	0.71	0.44	0.50	0.65

[1] Association measured by gamma.

increased frequency of "crowding and conflict" as a dissatisfaction reported before. Two explanations seem possible. First, visitors may be reacting more intensely to meeting more visitors than they prefer. In 1982, 20 percent listed "crowding and visitor conflicts" as a dissatisfaction, which nearly equals the 24 percent who said they met "too many," and most of these two crowding responses came from the same people. This type of shift in standards for solitude would be consistent with the shift from consumptive to nonconsumptive use styles previously described.

Second, the dissatisfaction answers seem to reflect conflict more than sheer numbers. In 1982, only 8 percent of the visitors listed crowding or sheer numbers encountered as a source of dissatisfaction and less than 1 percent listed too many other hunters, fishermen, or floaters. One percent mentioned other parties camped too close to them. Four percent listed how others behaved and 5 percent cited littering. But 7 percent cited "too many horse parties," and another 4 percent mentioned horse manure as a dissatisfaction (fig. 13). As mentioned before, the hikers were the source of almost all of the complaints about numbers of horse parties and manure. Eleven percent of the hikers complained of too many horse parties, and 6 percent about manure, compared to only 6 percent who reported meeting too many other visitors. Horseback travelers, in contrast, listed too many other visitors in 10 percent of the cases, too many horse parties only 1 percent, and manure 0.5 percent. Complaints about behavior of other visitors and about littering were both twice as common by hikers as horseback parties.

In 1970 there was a minor conflict between horse users and backpackers. But the conflict has grown as total use has increased, and as backpackers have increased and have become a larger proportion of Bob Marshall complex visitors relative to the long-established, traditional horse use. The backpackers have somewhat different expectations about wilderness conditions, as evidenced by their greater sensitivity to littering and inappropriate behavior.

Figure 13.—Complaints about the impacts caused by horses, particularly from hikers, grew from 1970 to 1982.

Numbers of encounters are fairly strongly associated with opinions of numbers met (table 25). In 1982, 44 percent of the variation in opinion of numbers met was accounted for by the average number met; in 1970, 45 percent. Other research (Stankey 1973) indicates that

Table 26.—Association of satisfaction[1] and measures of solitude, measured by gamma, Bob Marshall complex, 1970 and 1982

Measures of solitude	1970	1982
Average number of other parties met per day:		
All parties	−0.32	−0.17
Large parties	−.33	−.07
Horse parties	−.18	−.14
Success in finding campsite solitude	−.38	−.19
Perception of:		
Number of parties met	−.36	−.32
Impact conditions ("wear and tear")	−.31	−.35
Litter in area	−.07	−.24

[1] Satisfaction was coded 5 for A, 4 for B, etc., so a negative value for gamma means that as encounters increase or opinions become more unfavorable, satisfaction declines.

opinions about the numbers met were undoubtedly influenced also by the types of parties met (size of group, method of travel), where they were met (on trail or at campsite, near trailhead or deep in wilderness), and how they acted (considerate, etc.). In addition, visitors vary in their standards for acceptable levels of encounters; three per day could be just right for some people, but far too many for others. Thus, a very strong association between opinions of numbers met and average numbers met, considered in isolation, would not be likely.

If complaints about numbers met, types of visitors met, and so on, are indications of meaningful problems, one would expect that satisfaction should be affected. Some studies, almost all of wild rivers, have shown little or no association (Nielsen and Shelby 1977; Heberlein 1977; Graefe and others 1984). Studies of wildernesses with trail-oriented use, however, have shown stronger associations (Lucas 1980). This was the case in the Bob Marshall complex in both 1970 and 1982. All of the associations were negative, in the expected direction, ranging from weak up to moderately strong, although weaker in 1982 than in 1970 (table 26).

Because the 1982 questionnaire specifically asked about the importance of various wilderness appeals, it is possible to compare those who said solitude was very important to those who said it was not important. The relation of average number of parties met per day to satisfaction was about the same for both high and low solitude importance groups, contrary to expectations. Satisfaction was more related to feelings about numbers met (too many, about right, too few) for visitors for whom solitude was important than for those for whom it was not; gammas were 0.31 and 0.08, respectively. Also, the relation of feelings about numbers met to average numbers met per day was much stronger among the high-solitude-importance visitors; gamma was 0.57 for these visitors compared to 0.15 for low-solitude-importance visitors.

Previous research has shown that most wilderness visitors prefer not to meet larger parties and some would prefer not to meet horse parties (Stankey 1973). Most visitors to the Bob Marshall complex met few large parties. In 1970, 57 percent met none, and only 8 percent met over five large parties on their entire trip. In 1982 the figures were nearly identical—58 and 9 percent, respectively. Meetings with horse parties were more common. In 1970, only 23 percent met none, 63 percent met one to five other horse parties, and 14 percent met over five. In 1982, again the figures were very similar—26, 63, and 11 percent, respectively.

CAMPSITE SOLITUDE

Wilderness visitors find solitude at campsites more important than solitude while traveling (Stankey 1973). The fairly strong association between satisfaction and success in finding desired campsite solitude (table 26) also supports this conclusion, although, again, the association in 1982 is weaker than in 1970. Wilderness visitors usually prefer no other parties camped within sight or sound (Lucas 1980). The Bob Marshall complex visitors are no exception (table 27). There was a tendency for 1982 visitors to accept a few more nearby camps than 1970 visitors (fig. 14). Despite this more lenient standard in 1982, visitors said they had more trouble finding campsites that met their standard (table 27). Still, even in 1982, almost two-thirds of the visitors succeeded in camping where solitude conditions met their preference every night on their trip.

Table 27.—Number of other camps nearby desired by overnight visitors and success in finding such campsites, 1970 and 1982

	Camps desired				Success in finding desired campsite solitude		
Year	0	1	2	3 or more	Every night	Some nights	Never
	Percentage of total visits						
1970	86	7	4	3	76	18	6
1982	81±4	7	6	6	63	33	4

Figure 14.—Most visitors both years preferred a campsite isolated from the sight and sound of other campers.

PERCEIVED CHANGES IN AREA QUALITY

Visitors who have been to the Bob Marshall complex before can provide comparisons of changes in area conditions as they perceive them. Their comparisons may be helpful in assessing carrying capacity issues—are conditions becoming more deteriorated, stable, or improving in the view of experienced visitors? There is some good news; in 1970 over one-third of the experienced visitors felt conditions on their current trip were worse than on earlier visits, but in 1982 only 16 percent felt that way (table 28). The proportion feeling conditions were "about the same" rose from just over half in 1970 to just over three-fourths in 1982. Hikers and horse users differed very little.

Some of the changes mentioned before in use patterns toward smaller parties, and more even distribution among trailheads and over time may have contributed to this more favorable view of trends in area quality.

Visitors were also asked why they felt as they did about changes in area quality. The main reasons in 1970 were more crowding, more worn and littered conditions, and worse hunting and fishing, in that order (9, 5, and 3 percent, respectively, gave these answers). In 1982 it was quite different; complaints about trails became one of the main responses, but answers critical of crowding, fishing, and hunting dropped a little, and criticism of worn, littered conditions almost disappeared. Comments about litter in 1982 are interesting; less than 1 percent expressed negative views, and about as many said there was less litter than on earlier trips. Litter conditions are clearly perceived as improved (fig. 15).

Table 28.—Perceived change in area quality by repeat visitors, 1970 and 1982

Year	Area quality now, compared to earlier		
	Better	About the same	Worse
	Percentage of total visits		
1970	12	52	36
1982	8 ± 2	76 ± 4	16 ± 3

This is consistent with another question specifically about evaluation of litter conditions. In 1970, 65 percent rated litter conditions as good, but by 1982, 80 percent did. I believe that littering conditions actually are much better now than earlier, due to cleanup work by managers and improved visitor behavior, and it appears to be paying off in better visitor experiences.

In contrast, specific ratings of soil and vegetation impacts declined. In 1970, 22 percent rated such conditions fair to poor, but by 1982, 31 percent gave such negative evaluations. Campsites in the Bob Marshall Wilderness tend to have larger areas impacted and to exhibit more damage to trees than campsites in other wildernesses that have been studied (Cole 1983). These conditions were most objectionable to hikers, 36 percent of whom rated them as only fair to poor in 1982, compared to 21 percent of those traveling with horses. The increase in hikers may explain much of the increase in low ratings. Together with far more complaints about trail conditions, there is clearly a growing problem of visitor impacts (fig. 16).

Many of these problems of impacts and user conflicts potentially can be managed by regulating use, informing and educating visitors, and providing facilities. What do visitors think of some of these alternative actions, and how have their attitudes about them shifted?

RATIONING AND USE CONTROL

Visitors both years strongly supported "restricting the number of visitors to an area if it is being used beyond capacity," with over three-fourths answering that this is desirable, and only 12 to 14 percent saying it was undesirable. (Some visitors were neutral.) The question as worded is hard to disagree with; the contention would be over what visitors define as "beyond capacity."

Visitors were asked about several types of use control. One that was strongly rejected both years was issuing permits that listed assigned camping areas. In 1970, 75 percent rated this undesirable, and in 1982, 79 percent disapproved. Such tight regulation, which is similar to the system used in a few national parks, apparently was considered to take away too much freedom. Limits on party size were supported. In 1970 only 19 percent felt a 12-person-per-party limit was undesirable, and in 1982 just 22 percent expressed disapproval. (A 15-person limit was in effect in 1982. The 12-person party size wording was retained for comparability.)

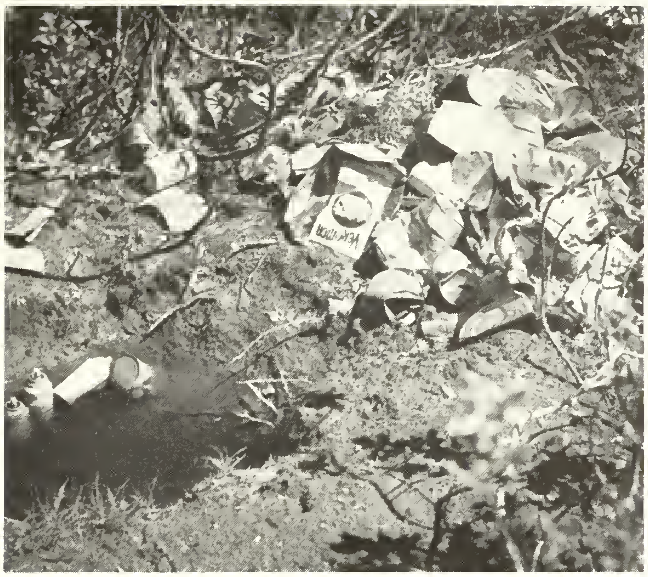


Figure 15.—Visitors perceived substantially less litter in 1982 than in 1970.

Figure 16.—Visitors rated both campsites and trails as more impacted by use in 1982 than in 1970.

"Closing some areas to horses" was favored by more than opposed it both years, but there was a strong tendency for visitors to respond in a self-serving way that highlights the conflict between different styles of use. For example, in 1982, 70 percent of the horseback visitors objected to such a policy, while 70 percent of the hikers favored it. Some horsemen (21 percent) favored such a policy, however, perhaps suggesting they believed that some areas were not well suited for horse use or that hikers should have some places to themselves.

"Prohibiting camping within 200 feet of water" was not asked in 1970 because it had not even been proposed then. By 1982 this was a regulation in a number of wildernesses, although not in the Bob Marshall complex. It was not supported by most Bob Marshall complex campers; 57 percent said it was undesirable, 9 percent were neutral, 10 percent said it was desirable in high-use areas, and only 24 percent favored it throughout the area. Horseback travelers and rafters were most negative, and hikers least negative, but all opposed this common regulation.

REGULATIONS

Other regulations, not directed at controlling use, were also studied. Requiring registration was favored about three to one, but more strongly in 1970 than in 1982.

"Prohibiting wood fires where dead wood is scarce (requiring use of gas stoves)" was opposed in 1970 by 46 to 31 percent, but favored in 1982, 48 to 41 percent. Campers, who are much more affected by a fire ban than day-users, were less favorable, and the 1982 margin of support by campers dropped to 46 percent in favor versus 43 percent opposed.

"Eliminating grazing by visitors' horses (require carrying horse feed)" was rejected by horse travelers, over three to one in 1970, and over two to one in 1982. The major difference was that in 1982 about 20 percent of the horse users answered that eliminating grazing was desirable in high-use areas, an answer that was not included in 1970.

"Allow visitors to catch fish to eat in the wilderness but not to bring out" was favored by 50 percent to 30 percent opposed in 1970 (with the rest neutral), and 58 to 26 percent in 1982. The idea behind this question was that catching a few fish for dinner can be an important part of a wilderness experience, but coming to catch a lot of fish to fill the freezer at home is an inappropriate, highly consumptive use. Because of its large size and remoteness, the Bob Marshall complex probably has less of this "stock the freezer" fishing than many wildernesses.

OTHER MANAGEMENT POLICIES

Wilderness rangers working in the field are well accepted, favored by almost a 5-to-1 margin both years. About one-third of the 1982 visitors said they met a "ranger" on their trip, although this probably includes some contacts with trail crews, game wardens, and others besides wilderness rangers.

Administrative use of chain saws for trail clearance was accepted, but by a wider margin in 1970 than 1982—about two to one in 1970, compared to 46 percent in favor and 32 percent against in 1982. Nine percent favored chain saw use only in high-use areas in 1982; 37 percent favored their use in general. A modest shift toward a somewhat more purist, less convenience-oriented view seems to have occurred.

The wilderness goal of a natural ecosystem, interfered with as little as possible by man, has tended to exhibit a double standard. Aquatic ecosystems have often been almost ignored, and stocking fish where none occurred naturally has been common, even with species of fish not native to the area. Visitors, however, either do not see the contradiction or accept it. "A natural fishery—no stocking and barren lakes left barren" was rejected by almost a 55 to 20 percent margin in 1970, and by 48 percent versus 28 percent in 1982. Still, there has been some shift toward a more ecologically oriented perspective.

"Natural forest fires started by lightning" were opposed in 1970 (45 percent against to 26 percent in favor), but favored in 1982 (49 percent in favor to 32 percent against). This is a major turnaround. Natural fire policies in wilderness were very new in 1970, and such a policy did not exist in the Bob Marshall complex. By 1982 such policies were more common, including the Bob Marshall complex, and people had had more opportunity to learn about it. Most seem to be accepting the idea; there was little variation in attitudes among visitors traveling in different ways, between hunters and nonhunters, and day-users and campers (fig. 17). Again, the more ecologically oriented view has gained strength.

Figure 17.—Natural fire and other natural ecological processes were supported by more visitors in 1982 than in 1970.

TRAILS

The major user facility in the Bob Marshall complex, as in most other wildernesses, is the trail system. A number of questions were related to trails and bridges.

"High standard trails (wide, steady grades, fairly straight)" were favored in 1970, but much more so in 1982 (table 29). Forty percent favored high standard trails only in high-use areas in 1982. Horseback travelers favored high standard trails more than did other types of visitors.

"Low standard trails (somewhat like a game trail—narrow, grade varies, winding, not the shortest route)" were favored by more than a 4-to-1 margin in 1970, and by over a 3-to-1 margin in 1982 (table 29). Hikers were more supportive than horse users. There seems to be growing support for higher standard trails, perhaps relating to the sharp increase in the frequency of complaints about trail conditions discussed before. In 1970, low standard trails had more support than high standard, but this was reversed by 1982. Technically, trail design standards (width, alignment, grade) are unrelated to maintenance condition (muddy spots, erosion, down trees), but respondents probably linked the two and may have responded largely in terms of maintenance conditions, which are recognized by managers as a problem.

"Leaving some areas with no trails" was strongly supported—by 70 percent in 1970 and 73 percent in 1982. Horseback travelers and hikers differed little on this issue.

"A few trees blown down across the trail, maybe one or two per mile" produced a wide split of opinion in 1970—35 percent said "desirable," 35 percent were neutral, 30 percent said "undesirable." In 1982, again, opinion was more supportive of higher standard trails—only 22 percent said "desirable," 37 percent were neutral, and 41 percent said "undesirable." Horseback travelers were the most negative.

"Bridges over creeks where hikers would otherwise get wet feet" were opposed by a small margin in 1970, but favored in 1982, especially in high-use areas, particularly by hikers.

"Bridges over rivers that are dangerous for hikers to wade or for horses to ford" were favored four to one in 1970, and over seven to one in 1982 (fig. 18).

All of these questions show the same trend—a growing desire for higher standard, safer trails in 1982 than in 1970. Some of this may be due to shifting visitor populations and some may result from deteriorating trail conditions encountered, but these two effects cannot be separated.

OTHER FACILITIES

"Outhouses (pit toilets)" were favored and opposed equally in 1970, but opposed almost two to one in 1982. "Cemented rock fireplaces" were opposed three to one in 1970 and over four to one in 1982. Loose rock fire rings were narrowly favored in 1970 but more strongly favored in 1982—47 percent in favor to 29 percent opposed (fig. 19). "Pole corrals for horses at campsites" were favored in 1970 by about four to three, and by a very narrow margin in 1982, with horsemen much more

Table 29.—Visitor opinions of high and low standard trails, 1970 and 1982

	High standard				Low standard			
Year	Desirable		Neutral	Undesirable	Desirable		Neutral	Undesirable
	Percentage of total visits							
1970	45		23	33	63		22	15
1982	A[1]	B			A	B		
	32 ± 3	40 ± 4	12 ± 3	16 ± 2	52 ± 4	7 ± 2	23 ± 4	18 ± 3

[1] In 1982, there were two possible desirable responses—A, "desirable," and B, "desirable in more heavily used parts of wilderness, but not in more lightly used parts."

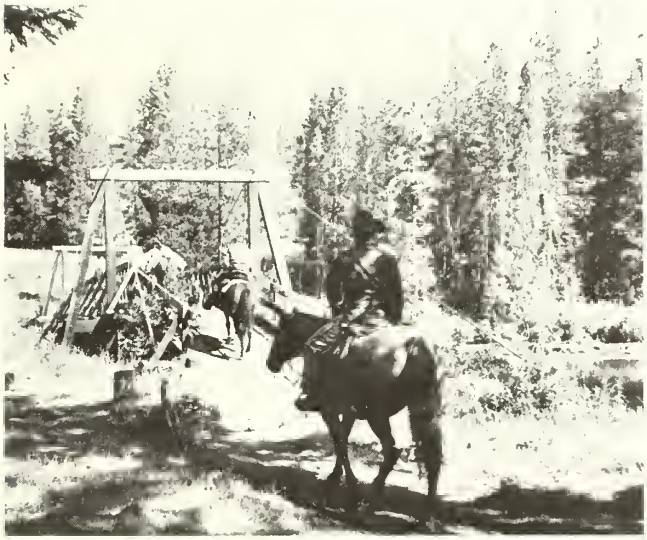


Figure 18.—Excepting bridges over large, dangerous rivers, most facilities received only limited support.

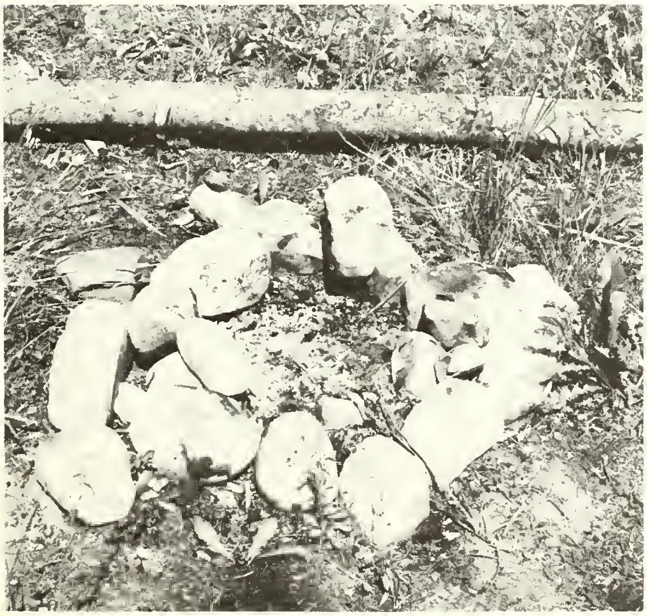


Figure 19.—Loose rock fire rings, high-standard trails, and bridges were the only facilities supported by more visitors in 1982 than in 1970.

favorable than hikers. Split log picnic tables were opposed two to one in 1970, over three to one in 1982.

Visitors do not seem to be in favor of more comfort and convenience items. Only the minimal loose rock fire rings received increased support in 1982 (the area has never had constructed fireplaces). This conflicts with managers' perceptions of fire rings as undesirable and efforts to remove them. Considered in the light of more purist standards for other facilities and for ecological conditions, the support for higher standard trails seems inconsistent at first glance. It is possible that it is a protest against trail conditions that are widely recognized as poor.

INFORMATION SOURCES

In using information as a management tool, it is helpful to know what visitors think of some means of providing information.

Guidebooks were strongly supported (about 10 to 1), a bit more so in 1970 than 1982. Detailed, accurate maps were almost universally considered desirable both years.

Onsite information in the form of signs explaining natural features or historical events were opposed in 1970 by about two to one, but were favored by a small margin in 1982. It is possible that although the question was worded to exclude directional trail signs, some respondents still thought of directional signs. If so, it may be one more indication of the concern about trail conditions. Complaints about lack of directional signs were common, especially from horse travelers.

Visitors who said they had contacted the Forest Service in 1982 were asked how well the information they got met their needs; 51 percent said "very well," 36 percent said "fairly well," and 13 percent said "not very well." As described before, wilderness rangers are well accepted.

ACCEPTABLE VISITOR BEHAVIOR

Wilderness managing agencies have worked hard to educate visitors in minimum-impact wilderness use techniques. Several questions provide a chance to see how much effect this education has had.

"Pack it in, pack it out" is one of the messages used longest, and there are signs of progress. In 1970, most visitors said burying unburnable garbage was desirable, but in 1982, over two to one said it was undesirable. In 1982, visitors were also asked about "packing unburnable garbage out of the wilderness." Over 90 percent said this was desirable (although 30 percent also said, on the earlier question, that burying it was desirable). Almost no one was neutral on any of the questions about garbage.

Two questions about campfires were asked only in 1982 as the issue of campfire impacts has become of more concern. Visitors responded overwhelmingly (over 5 to 1) that campers should "use only dead wood on the ground for campfires." Hikers were more supportive than horse parties, who, of course, can more easily carry saws and axes. Visitors were also asked about "encouraging visitors to remove fire rings and all evidence of campfires when breaking camps." About 60 percent of campers said this was desirable, 21 percent said undesirable, and 18 percent didn't care, although most campers had said loose rock fire rings at a campsite were desirable. Perhaps many wilderness campers know the recommended practice but follow it poorly because they do not consider fire rings an undesirable mark on the land.

Summary of Attitudes

Some attitudes shifted sharply, some moderately, and some very little from 1970 to 1982. The sharp changes were mainly related to trails. Complaints about poor trails shot up sixfold, and support for high standard trails and bridges grew substantially. Support for allowing some lightning fires to burn also increased markedly. Crowding and conflict, particularly hiker dissatisfaction with horse users, grew substantially.

There were moderate shifts in reasons for visiting the wilderness, paralleling the shift in activities from more consumptive to more contemplative. Numbers of other visitors met per day grew moderately. Except for trails, attitudes moved in the direction of fewer facilities and improvements, and toward support for more natural ecosystems. Minimum impact use practices were accepted more in 1982. There was less littering. Vegetation and soil impacts were perceived as deteriorating. Desired campsite solitude was harder to find.

Little or no change occurred in the importance visitors attached to wilderness, their satisfaction levels, factors satisfying visitors, feelings of crowding, campsite solitude standards, and attitudes toward most regulatory actions, such as support for rationing use, opposition to assigned campsites, and support for party size limits, trailless areas, and for wilderness rangers.

SUMMARY

1. More Backpackers

The growth in backpacking is the major shift in recreational use of the Bob Marshall complex from 1970 to 1982. In 1970, visitors traveling with horses outnumbered hikers about 3 to 2. By 1982, the balance was reversed and hikers outnumbered horse users about 3 to 2. From 1970 to 1982, horse use grew, probably about 20 percent, while hiker use grew well over 100 percent. This change is the key to many of the other changes in use patterns, visitor characteristics, and attitudes. Few of the changes are large ones, however, and overall there is considerable stability in the recreational situation in this large wilderness complex.

2. Lower Impact Potential

Use characteristics have shifted toward a slightly lower potential for resource impacts. In addition to the shift to predominantly backpacker use, parties are smaller, stays are shorter, and there is slightly less fishing and hunting, and more photography and nature study. Visitors have become less dependent on wood fires. Weekend peaks in use have become less pronounced. Use has become less concentrated at popular places.

3. Shifts Not Linked to Impacts

Other changes, not necessarily related to the potential for impacts, are a larger proportion of visitor use in the summer rather than fall, a smaller proportion of visitors with outfitters, a little less observation of wildlife, and a smaller proportion of hunters taking game.

4. Typical Use Still Similar

Typical use in 1982 still consists of long trips—long in days (about 5) and distance covered (20 to 30 miles [33 to 50 km])—by small parties, most with fewer than five people. The typical visitor now is hiking, but nevertheless almost 40 percent of the visitors are using horses—an unusually high percentage. The typical visitors come in the summer; are on their own without an outfitter; go fishing, photographing, and do a few other things; see some deer and perhaps other large mammals; and enter at one of a few popular trailheads. Except for the shift from horse to hiker, this sketch would apply generally in 1970 about as well as in 1982; the changes are modest.

5. User Characteristics Changed Little

The kinds of people who visit the Bob Marshall complex were very similar in 1970 and 1982. The major shift, and even it is not really large, is toward a higher percentage of nonresidents as the wilderness has become more widely known for a variety of types of recreation, not just elk hunting. But more than half of the visitors are still Montanans, usually from northwestern Montana. Women make up a larger proportion of visitors in 1982 than in 1970. The high education levels in 1970 were even higher in 1982 and even more visitors were in professional and technical occupations. A number of characteristics remained essentially unchanged: most visitors are from urban areas, are family groups, are young adults, and more than three-fourths have visited wildernesses before (but more were making their first visit to the Bob Marshall complex in 1982 than in 1970, particularly for backpackers). Few contact the Forest Service managers of the area for information, but most have maps. Less than one-tenth belong to a wilderness-oriented club, and most do not belong to outdoor recreation or conservation organizations.

6. Trail Complaints and More User Conflict Main Attitude Changes

Two changes stand out among visitor attitudes. The most pronounced is far more complaining about trail conditions and more support for higher standard trails. Less intense, but still growing, is conflict among hikers and horse users. Hikers, in particular, express more objections to horses and their impacts in 1982 than in 1970. There appears to be a small shift in motives for visiting wilderness, paralleling the shift in activities from more consumptive (hunting and fishing) to more contemplative appeals (scenery, relaxation, escaping civilization). Solitude and avoidance of mechanized recreation were moderately strong both years.

7. Solitude Diminished But Still High

Most visitors met relatively few other visitors, averaging only a little over one other party per day, but nevertheless encounters were more frequent in 1982. A campsite isolated from others was a little harder to find in 1982, but still about two-thirds found it.

8. Less Litter, More Impacts

Experienced visitors felt overall conditions were more stable, less often deteriorating in 1982 than in 1970. Visitors perceived littering to be less of a problem in 1982, but felt that impacts to vegetation and soils were worse.

9. More Purist Attitudes, Except Toward Trails

Visitor attitudes about management policies and practices showed some shift toward a more natural wilderness ecologically, with less support for facilities and improvements, except trails, where there was a strong shift toward higher standard trails and bridges—a seeming anomaly that probably is linked to the great increase in complaints about trail conditions. Awareness of appropriate, low-impact camping practices grew from 1970 to 1982.

10. Satisfaction and Many Other Attitudes Stable

Both years, most visitors attached high personal importance to wilderness, and reported high levels of overall satisfaction, with similar reasons for satisfaction. There was little or no change in attitudes about most regulations. Desirable campsite solitude standards were close both years.

MANAGEMENT IMPLICATIONS

1. A Chance to Catch Up

Wilderness managers many places have often felt overwhelmed. Use was growing rapidly, conditions were deteriorating, and problems were compounding. Managers felt as though they were on a treadmill that kept speeding up. This does not seem to be the case in the 1980's in the Bob Marshall complex. Use patterns have shifted toward activities with lower impacts; visitors know more about minimizing impacts; litter has lessened; and although use has increased, the rate of growth in use has probably slowed and may slow more in the future. If managers can solve the problems they face in the area, the gains need not be quickly swamped by new use pressures.

2. Trails the Main Problem

The main problem stands out sharply: bad trail conditions, particularly mudholes and erosion. All types of visitors agree on this; it is not a hiker versus horse user problem. The solutions include more maintenance, reconstruction, and relocation. Lack of money and personnel are the main constraints.

3. Campsite Impacts Also a Problem

There also are indications from visitors that campsite impacts to vegetation and soil are a growing concern. Closure of some campsites, their replacement by more durable sites, and continued stress on educating visitors in minimum impact camping practices are the main elements in solutions (Cole 1983). Monitoring of campsite conditions will also be essential. Some regulations, for example group size limits, may need to supplement education, at least until new norms for visitor conduct are established.

4. User Conflict a Growing Concern

The third problem is the growing conflict between hikers and horse users. It is not extreme, but efforts to reduce it seem warranted by visitors' reactions. The solutions are neither clear nor simple. Education must be a major element. Education programs could strive to reduce conflicts (by not keeping horses right in camp, or by hikers giving horses the right of way, for example), and also to build more understanding and tolerance of other types of visitors. Publicizing where horse use is common and where it is not might help particularly sensitive hikers to reduce their contacts with horse parties.

5. Natural Role of Fire Accepted

Visitor acceptance of natural, prescribed fire has grown, and does not seem to be a serious barrier to allowing fire to more nearly play its natural role.

6. Visitor Education Has Advantages

High education levels and commitment to wilderness should render visitors particularly amenable to management through informational programs.

7. Successes

A lot of management efforts seem to be working, for example litter control and cleanup. Visitors still experience high levels of solitude, see wild animals, and report high satisfaction overall with their wilderness experiences. Comparisons of many earlier and later conditions suggest that managers "keep up the good work."

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Trends from 1970 to 1982 in the Bob Marshall Wilderness complex of three adjacent wildernesses were analyzed. Data on use characteristics, use distribution, visitor characteristics, and visitor attitudes were compared. The greatest changes were increases in hiker use compared to horse use, and much more dissatisfaction with trail conditions.

KEYWORDS: wilderness, trends, recreational use, use distribution, visitor characteristics, visitor attitudes, satisfaction, carrying capacity

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Research Paper
INT-346

June 1985

Ten-Year Results of Fertilizing Grand Fir, Western Hemlock, Western Larch, and Douglas-fir with Nitrogen in Northern Idaho

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CLEMSON UNIVERSITY
SEP 5 1985
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ACKNOWLEDGMENT

As in any long-term study, many individuals have contributed to its successful completion. The most prominent include Glenn Deitschman who started the study, Ray Boyd, and the late Marvin Foiles, all research silviculturists who provided continuity and valuable assistance.

RESEARCH SUMMARY

Forest fertilization is a successful cultural treatment for increasing forest yields. However, research has shown wide variability in response of forest stands to the application of fertilizer. Results of most studies on nitrogen fertilizer, the most commonly applied nutrient, are highly dependent on site and species.

This study also shows high variability that can be expected from the application of fertilizer. Ten years after the application of nitrogen fertilizer in the form of urea at 200 and 400 lb per acre, only short-term differences in tree growth could be detected between fertilized and unfertilized trees. No major differences were evident after 10 years. Grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.) had the best response to fertilizer 5 years after application with a 45 percent increase in diameter growth at that time. Fertilized western white pine (*Pinus monticola* Dougl.) were growing slower than the unfertilized pine after either 5 or 10 years. How tree species respond to the application of fertilizer may be related to their successional position in a stand and their tolerance to different ranges or levels of nitrogen nutrition.

Ten-Year Results of Fertilizing Grand Fir, Western Hemlock, Western Larch, and Douglas-fir with Nitrogen in Northern Idaho

Russell T. Graham
Jonalea R. Tonn

INTRODUCTION

Forest fertilization has become an accepted management tool for increasing merchantable volumes of forest stands in many areas of the country. However, there is reluctance to apply fertilizers operationally because of inconsistent growth responses and because of a paucity of information on the response of forest stands to fertilization, particularly in the Northern Rocky Mountains.

Nitrogen, usually the most growth-limiting nutrient of forest soils, is the most commonly applied fertilizer. The addition of other elements, such as phosphorus, potassium, and sulfur, seldom improves gains achieved from applying nitrogen alone (Gessel and others 1965; Heilman 1971; Miller and Reukema 1974). Nitrogen is usually applied in the form of urea that contains 46 percent nitrogen, or in the form of ammonium nitrate that contains 34 percent nitrogen.

The site on which fertilizer experiments are located can influence results. Usually, better growth responses to fertilizer occur on poor sites (Miller and Fight 1979). But often, as Miller and Reukema (1974) found, good sites also have excellent response to application of fertilizer. They reported ammonium nitrate applied at 300 lb per acre significantly increased growth of 75-year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) on a highly productive site in western Washington. In contrast, Graham and Tonn (1979) reported no increase in growth attributable to the application of nitrogen fertilizer on western white pine (*Pinus monticola* Dougl.) on a good site in northern Idaho. Webster and others (1976) reported poor growth responses to the application of nitrogen fertilizer on western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) along the Pacific coast. On inland sites, they reported a good response.

How an individual species reacts to the application of fertilizer can also be highly variable. As noted earlier, western white pine in one study in northern Idaho did not respond to nitrogen fertilizer, while in another (Ryker and Pfister 1967) there was a 39 percent increase in the diameter growth of nitrogen-fertilized western white pine over unfertilized pine. Similarly, Loewenstein and Pitkin's study in northern Idaho (1963) reported nitrogen-fertilized western white pine with a 187 percent increase in height growth, as compared to unfertilized pine. Scanlin and others (1976) reported a 61 percent growth increase of grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.) due to nitrogen fertilizer application in northern Idaho. Loewenstein and Pitkin (1963) also reported a 286 percent response to the application of nitrogen fertilizer on grand fir in northern Idaho.

As these examples show, the results of fertilizer trials are highly variable. They also show how uncertain the results from the application of fertilizers can be. Therefore, the surest way to select areas for operational fertilization is to match stand and soil characteristics of successful, experimental field trials (Miller and Fight 1979).

This study was undertaken to document the results of nitrogen fertilization in two stands on experimental forests chosen as representative of good sites in northern Idaho. We reasoned that stands of proper age, growing on sites with no likely moisture or other nutrient limitations to growth, might respond well to the application of readily available nitrogen.

STUDY DESIGN

Two fertilization studies were established in young, natural stands of mixed conifers in the *Tsuga heterophylla/Pachystima myrsinites* habitat type (Daubenmire and Daubenmire 1968). One was located at the Deception Creek Experimental Forest (DCEF), and the other was at the Priest River Experimental Forest (PREF). Both represent excellent forest sites in northern Idaho.

The DCEF study, on a north aspect, in lower Snyder Creek was 4.5 acres in size. Slope angles ranged from gentle to 50 percent. The soils of the area are inceptisols overlaying gneiss parent material. The stand developed under seed trees from a 1952 cutting. The seed trees were removed in 1965, and in 1971 the stand was cleaned to a 10-foot-square spacing. A uniform stand of dominant and codominant trees remained. Species represented in the stand included:

western white pine
western larch (*Larix occidentalis* Nutt.)
Douglas-fir
grand fir
western hemlock
Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)
subalpine fir (*Abies lasiocarpa* [Hook.] Nutt. var. *lasiocarpa*)

The plots at DCEF were fertilized in fall 1972. At that time the stand had a mean diameter of 1.4 inches and a mean height of 10.7 feet.

The DCEF study was designed as a randomized complete block with five blocks, each having three treatments. The treatments were randomly assigned to 0.5-acre treatment units as:

Treatment 1: no fertilization

Treatment 2: urea applied by hand spreader at the rate of 200 lb of N per acre

Treatment 3: urea applied by hand spreader at the rate of 400 lb of N per acre

Subplots of 0.04 acre were established within the treatment units, and trees within the subplots were tagged and measured.

The PREF study was on 3 acres in the lower part of the Benton Creek Drainage. The stand originated in 1955 after cutting of the previous stand and dozer clearing of the area. Slope angles ranged from 25 to 35 percent. The stand is growing on soils classified as typic cryochrept and derived from gneiss parent material. After a cleaning in fall 1971 to a 12-foot-square spacing, a uniform stand of the following species was left:

western white pine
western larch
Douglas-fir
lodgepole pine (*Pinus contorta* Dougl. ex Loud.)
western hemlock
western redcedar (*Thuja plicata* Donn ex D. Don)
Engelmann spruce
ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*)

Fertilization at PREF took place early in spring 1973. At that time, the mean stand diameter was 3.3 inches and the mean height was 21.7 feet.

At PREF a randomized complete block design was used with three blocks each having two treatments. In contrast to the DCEF study, only two treatments were randomly assigned to 0.5-acre treatment units, as follows:

Treatment 1: no fertilization

Treatment 2: urea applied by hand spreader at the rate of 200 lb of N per acre

Subplots of 0.1 acre were established within the treatment and the trees within them tagged and measured.

At both areas, diameter at breast height (d.b.h.) and total height of the tagged trees were measured in 1973, 1974, 1977, and 1982. Periodic mean annual diameter growths and periodic mean annual height growths for 1973 to 1977 and 1977 to 1982 were computed for the trees remaining in 1977 and 1982, respectively.

An analysis of covariance was used to analyze the data for each study area. Because tree size at the time of treatment influences subsequent growth, individual tree d.b.h. at the time of establishment was used as a covariate for analyses involving diameter, and individual tree height at the time of establishment was used as a covariate in the analyses involving heights. The dependent variables used in the analyses included d.b.h., height, and periodic mean annual height growth and periodic mean annual diameter growth for 0 to 5 and 5 to 10 years after treatment. Those species that had adequate observations to analyze alone included grand fir at DCEF and western white pine, western larch, and Douglas-fir at PREF. Various analysis of covariance tables were created (table 1). In all cases, if the F test in the analysis detected significant differences ($p \leq 0.05$) between the treatment means, the least squares mean separation procedure was used to locate the differences (SAS Institute 1982).

RESULTS

The results of this study reveal how mixed-species stands of conifers respond to the application of nitrogen fertilizer in northern Idaho, and how nitrogen fertilizer affects the diameter and height growth of four species. In addition, these results show the inconsistent growth responses that can be expected when applying fertilizer to forest stands.

Table 1.—Analysis of covariance

	Degrees of freedom							
	Deception Creek Experimental Forest		Priest River Experimental Forest					
Source	All trees	Grand fir	All trees	Western white pine	Western larch	Douglas-fir	Expected mean squares
Treatments	2	2	1	1	1	1	$\sigma^2 + s\sigma_\epsilon^2 + sr \Sigma \tau_i^2/(t-1)$
Blocks	4	4	2	2	2	2	$\sigma^2 + s\sigma_\epsilon^2 + st \Sigma \beta_i^2/(r-1)$
Block * treatment (experimental error)	8	8	2	2	2	2	$\sigma^2 + s\sigma_\epsilon^2$
Sampling error	200	96	170	16	28	69	σ^2
Covariate (initial height or initial d.b.h.)	1	1	1	1	1	1	
Total	215	111	176	22	34	75	

Deception Creek Experimental Forest

The increased growth rates brought about by application of fertilizer were short-lived. Five years after treatment, trees of all species fertilized with nitrogen had a periodic mean annual diameter growth[1] 24 percent larger than unfertilized trees (table 2). There were no significant differences ($p \leq 0.05$) in diameter growth means detected between the 200- and 400-lb-per-acre fertilizer treatments. In contrast, during the 5 to 10 years after treatment, no significant differences in diameter growth were found due to fertilization between any of the three treatments (table 2).

During the first 5 years after treatment, trees in the two fertilized treatments also had significantly ($p \leq 0.05$) larger periodic mean annual height growths than the unfertilized treatment. An 18 percent significant difference existed in the height growth means observed between unfertilized and 400-lb-per-acre treatments, but no significant difference occurred in height growth means between the two levels of fertilizer. As with diameter growth, no differences in height growth were apparent during the 5 to 10 years following treatment.

Grand fir alone had growth patterns similar to the stand as a whole. Five years after treatment, a 30 percent difference (significant at $p \leq 0.05$) in periodic mean annual diameter growth was detected between the unfertilized and 200-lb-per-acre treatments (table 2). No significant differences in the means for diameter growth were observed between the two fertilizer treatments. During the second 5 years, no significant differences between the treatment means for diameter growth were detected.

Periodic mean annual height growth for grand fir was also influenced by the application of fertilizer for only the first 5 years (table 2). There was a 45 percent difference in height growth means between the unfertilized grand firs and those treated with 400 lb per acre of nitrogen. Even though there was a 17 percent difference between height growth means for the two levels of fertilizer, the difference was not statistically significant ($p \leq 0.05$). No significant differences among the annual height growth means could be detected 10 years after treatment (table 2).

Priest River Experimental Forest

At PREF, the application of nitrogen fertilizer had little influence on tree growth. During the first 5 years after treatment, no significant differences ($p \leq 0.05$) in periodic mean annual diameter growth were found with application of fertilizer (table 3). Likewise, during the second 5 years after treatment, no significant differences were detected in diameter growth between the fertilized and unfertilized trees.

However, a significant response occurred in the fertilized trees in periodic mean annual height growth during the first 5 years after fertilization. The fertilized trees had a 9 percent larger growth mean than the unfertilized ones (table 3). As with treatments at DCEF, there were no significant differences in annual height growth means during the second 5 years after treatment.

Western white pine did not respond positively to the application of nitrogen fertilizer at PREF. Furthermore, the unfertilized western white pine actually had a larger periodic annual diameter growth mean than the fertilized pine (table 3) during the first 5 years after treatment. Neither diameter growth means nor periodic annual height growth means for the two treatments were significantly different during the first or second 5 years after treatment.

Western larch at PREF also had little response to fertilizer, similar to western white pine. No significant differences in periodic annual diameter growth means were observed either 5 or 10 years after treatment (table 3). Also, no differences in the periodic annual height growth means were detected between the fertilized and unfertilized trees.

The only species at PREF that showed a positive response to fertilization was Douglas-fir. The periodic annual height growth mean 5 years after treatment for 200-lb-per-acre was significantly larger (17 percent) than the mean for the unfertilized treatment, while 10 years after treatment, no differences in height growth were detected. No significant differences were detected

Table 2.—Periodic mean[1] annual diameter growth and periodic mean annual height growth for all species and for grand fir at Deception Creek Experimental Forest

	All species				Grand fir			
	Diameter		Height		Diameter		Height	
Treatment[2]	0-5[3]	5-10	0-5	5-10	0-5	5-10	0-5	5-10
	Inches		*Feet*		*Inches*		*Feet*	
1	0.29a[4]	0.28a	1.14a	1.51a	0.27a	0.26a	1.10a	1.33a
2	.36b	.28a	1.25b	1.71a	.35b	.27a	1.36b	1.93a
3	.36b	.31a	1.35b	1.58a	.34b	.31a	1.59b	1.87a

[1] All means are least square means. Diameter growths are adjusted for diameter at beginning of the study and height growths are adjusted for height at the beginning of the study.
[2] Treatment 1 = no fertilizer, 2 = 200 lb N/acre, 3 = 400 lb N/acre.
[3] Time since treatment in years. There are no significant differences ($p \leq 0.05$) in the means between time periods.
[4] Different letters following means indicate significant differences ($p \leq 0.05$) between treatments.

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[1] All means reported are least square means adjusted by covariate analysis for initial differences at the beginning of the study.

Table 3.—Periodic mean[1] annual diameter growth and periodic mean annual height growth for all species, western white pine, Douglas-fir, and western larch at Priest River Experimental Forest

	All species				Western white pine				Douglas-fir				Western larch			
	Diameter		Height		Diameter		Height		Diameter		Height		Diameter		Height	
Treatment[2]	0-5[3]	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10
	-- Inches --		---- Feet ----		--- Inches ---		---- Feet ----		--- Inches ---		---- Feet ----		--- Inches ---		---- Feet ----	
1	0.36a[4]	0.31a	2.00a	2.13a	0.46a	0.39a	2.58a	3.06a	0.40a	0.34a	1.84a	1.95a	0.23a	0.27a	1.98a	2.05a
2	.37a	.31a	2.18b	2.05a	.37a	.37a	2.68a	2.64a	.42a	.33a	2.15b	1.88a	.28a	.26a	1.98a	2.19a

[1] All means are least square means. Diameter growths are adjusted for diameter at beginning of the study and height growths are adjusted for height at the beginning of the study.

[2] Treatment 1 = no fertilizer, 2 = 200 lb N/acre.

[3] Time since treatment in years. There are no significant differences ($p \leq 0.05$) in the means between time periods.

[4] Different letters following means indicate significant differences ($p \leq 0.05$) between treatments.

between the periodic annual diameter growth means for Douglas-fir for either the first or second 5 years after treatment.

TREE SIZE

At DCEF, nitrogen fertilization did not significantly influence tree size of the entire mixed stand (table 4). No significant differences ($p \leq 0.05$) in either diameter or height were detected among the treatments 10 years after fertilization. The grand fir fertilized with 400 lb per acre had a mean diameter 15 percent larger than the unfertilized grand fir, and those fertilized with 200 lb of nitrogen per acre were 12 percent larger than unfertilized grand fir. But no differences in mean heights were found between the treatments of grand fir at the end of 10 years.

There were also no differences in mean heights or mean diameters between the fertilized and unfertilized trees for the entire stand at PREF (table 5) 10 years after fertilization. Among the species at PREF, the only significant difference in mean diameter 10 years after treatment was for western white pine. In that case, the unfertilized trees had a larger diameter mean than the fertilized ones. No differences in mean heights or diameters existed 10 years after treatment for either western larch or Douglas-fir.

DISCUSSION

The application of nitrogen fertilizer in the form of urea to young stands of mixed conifers growing on the *Tsuga heterophylla/Pachistima myrsinites* habitat type in northern Idaho does not appear to be that beneficial. Growth responses were highly variable and short-lived. For the most part, the only significant growth response to the application of nitrogen fertilizer occurred on grand fir at the DCEF study site. The results were even less impressive at the PREF site, where only a moderate height growth response to fertilizer was noted. In addition, at PREF the fertilized western white pines were growing more slowly than unfertilized trees.

From these results, it appears that nitrogen was not limiting at either location. Because both are good growing sites with deep soils and good organic reserves, the sites probably have adequate nitrogen available. In addition, the stand cleaning that occurred prior to the fertilization was done in a timely manner, resulting in a uniformly spaced stand of dominant and codominant trees, each having adequate growing space. This probably resulted in a microenvironment for each tree that had sufficient nitrogen for good growth and development of the species present.

The exception to poor growth responses from application of fertilizer was grand fir. At DCEF, grand fir responded well, but with a duration of less than 10 years. Grand fir is a shade-tolerant, late-successional species compared to the white pine and Douglas-fir that also occupy these sites. Grand fir may be similar to other late-successional species in that it can tolerate low levels of soil nitrogen, but may be more nitrogen demanding during aggressive growth. The amplitude of its growth response curve to nitrogen nutrition may be high over a wide range of nitrogen levels. If grand fir could become nitrogen demanding, it would increase its growth rates when nitrogen fertilizer is applied under good growing conditions. In contrast, a species such as western white pine may have a growth response curve with a low amplitude, making it tolerant to a narrow range in levels of nitrogen. Therefore, on a good site, western white pine would be less likely to respond to fertilizer than grand fir.

Although this study adds to the literature on fertilization of forest stands in the Northern Rocky Mountains, it continues to show that a wide range of growth responses can be expected. On good sites in northern Idaho, application of fertilizer to grand fir appears to be of some value, but application to other species does not appear to be warranted. Additional work on poor sites is currently under way.

Table 4.—Diameter at breast height (d.b.h.), and height means by treatment for all trees and for grand fir at Deception Creek Experimental Forest

Treatment	1972 d.b.h.	1982 d.b.h.	1982 adj. d.b.h.[1]	1972 height	1982 height	1982 adj. height[1]
	Inches			*Feet*		
			All species			
1[2]	1.3	4.1	4.3a[3]	10.0	22.9	23.8a
2	1.5	4.8	4.7a	11.1	26.1	25.6a
3	1.5	5.0	4.8a	11.0	26.1	25.4a
			Grand fir			
1	1.3	3.9	4.1a	9.7	22.2	22.4a
2	1.5	4.7	4.6b	10.7	27.3	27.1a
3	1.5	4.8	4.7b	10.5	27.7	27.6a

[1] These means are least square means. Diameters are adjusted for diameter at the beginning of the study and heights are adjusted for height at the beginning of the study.

[2] Treatment 1 = no fertilizer, 2 = 200 lb N/acre, 3 = 400 lb N/acre.

[3] Different letters following means indicate significant differences ($p \le 0.2105$) between treatments.

Table 5.—Diameter at breast height (d.b.h.) and height means by treatment and species at Priest River Experimental Forest

Treatment	1972 d.b.h.	1982 d.b.h.	1982 adj. d.b.h.[1]	1972 height	1982 height	1982 adj. height[1]
	Inches			*Feet*		
			All species			
1[2]	3.2	6.4	6.6a[3]	20.9	41.1	42.1a
2	3.4	6.7	6.7a	22.4	43.5	42.8a
			Western white pine			
1	3.4	7.7	7.9a	20.8	49.0	49.4a
2	3.5	7.2	7.2b	21.2	47.9	47.3a
			Western larch			
1	3.0	5.4	5.6a	24.1	44.0	45.0a
2	3.2	5.9	5.9a	25.5	46.1	45.9a
			Douglas-fir			
1	3.6	7.3	7.2a	20.8	39.7	40.1a
2	3.4	7.1	7.3a	21.2	41.5	41.3a

[1] These means are least square means. Diameters are adjusted for diameter at the beginning of the study and heights are adjusted for height at the beginning of the study.

[2] Treatment 1 = no fertilizer, 2 = 200 lb N/acre.

[3] Different letters following means indicate significant differences ($p \le 0.05$) between treatments.

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Ten-year results show initial short-lived increase in growth at two locations where nitrogen fertilizer in the form of urea was applied to young stands of mixed conifers in northern Idaho. In the second 5 years after treatment there were no further significant ($p \leq 0.05$) increases between the fertilized and unfertilized trees in either diameter or height growth. Grand fir (*Abies grandis*) responded better in the first 5 years than any other species, while western white pine (*Pinus monticola*) and western larch (*Larix occidentalis*) showed no evidence of response during the 10-year study.

KEYWORDS: fertilization, western white pine, grand fir, western larch, Douglas-fir, diameter growth, height growth

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United States
Department of
Agriculture

Forest Service

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Research Paper
INT-348

August 1985

Attaining Visual Quality Objectives in Timber Harvest Areas—Landscape Architects' Evaluation

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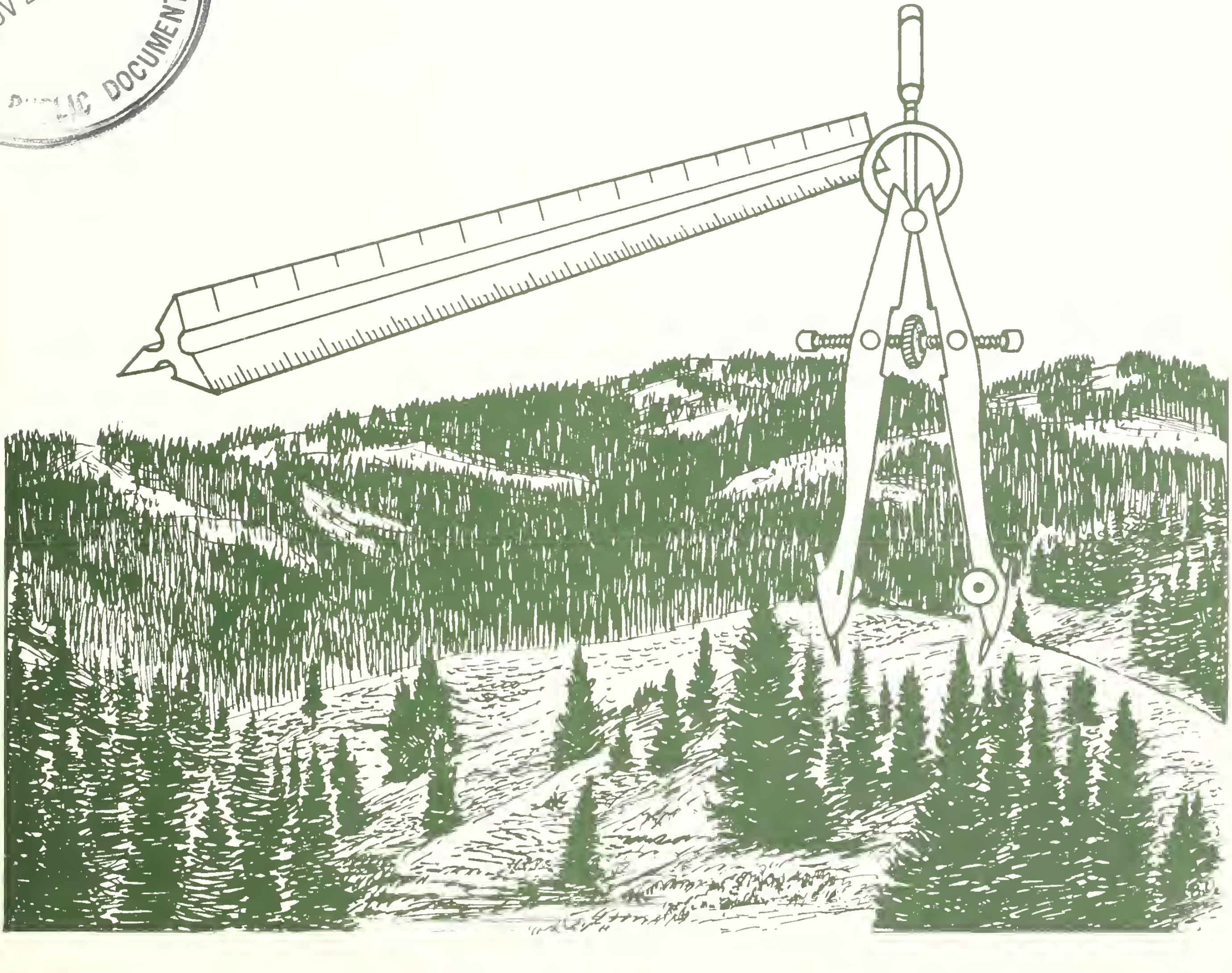

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RESEARCH SUMMARY

When management activities such as timber harvest are undertaken on National Forest lands, landscape architects establish plans and guidelines so the project will meet a desired level of visual quality. This visual quality objective (VQO) for a given project is based on forest conditions, topography, and the type of viewing that is anticipated (viewing distance, number and type of visitors, etc.). Although landscape architects provide criteria and guidelines to achieve these visual objectives, there is no direct feedback mechanism with which to monitor the public's reaction or ascertain the extent to which visual objectives are met.

In this study, 25 timber harvest areas (five in each of five VQO categories) in the Northern Rocky Mountains were selected by sampling timber sales and photographed with color slides. Landscape architects from three Forest Service Regions then evaluated these slides twice: (1) to judge the level of VQO they perceived to have been attained, and (2) to express their preferences for the areas on the like-dislike scale. Their ratings were mathematically transformed to adjust for variations among the slides used to represent each area, and differences among individual landscape architects in how they used the rating scale.

Results indicated that the VQO planned was usually, but not always, achieved. When individual areas were regrouped on the basis of the landscape architects' consensus of the VQO achieved, there was a close agreement among all three groups as to their perception of VQO category. The three groups were also in close agreement as to their preference ranking for different areas. There were sharp (and statistically significant) differences in the ratings given to two of the most visually evident categories—modification and maximum modification. The three other categories (preservation, retention, and partial retention) were all given higher preference ratings, but differences were not statistically significant among these three categories.

These results indicate that landscape architects can readily distinguish between areas that have varying degrees of visual impact from harvesting, and that less disturbed areas are preferred to those with heavier visual impact. In addition it indicates that some levels of management (retention and partial retention) can be undertaken so they are as visually pleasing as undisturbed (preservation) areas.

Attaining Visual Quality Objectives in Timber Harvest Areas—Landscape Architects' Evaluation

Robert E. Benson
Stephen F. McCool
Joyce A. Schlieter

INTRODUCTION

During the past two decades there has been a growing interest in the effects of forest land management activities on the visual quality of the landscape. The Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976 direct that harvesting on National Forests will be done so as to protect all forest resources, including the visual resource.

The Forest Service has developed a Visual Management System that provides guidelines to mitigate visual effects of various management activities such as timber harvest, road building, or siting of facilities like powerlines and buildings. The objective of the system is to ". . . manage all National Forest System lands so as to obtain the highest possible visual quality commensurate with other appropriate uses, costs, and benefits" (Forest Service Manual 2380.2). Based on landscape characteristics and expected public use, visual quality objectives are developed and guidelines prescribed for accomplishing these objectives.

In planning the visual objectives for a project, the landscape architect in effect acts on behalf of the viewing public. If there is public concern for viewing, this concern is reflected and linked to the project by the landscape architect's plans and guidelines. It is assumed that the visual quality perceptions of the landscape architect correspond to those of the general public; and that, furthermore, the visual objective desired will be accomplished on the ground.

A considerable amount of research (over 200 studies) has been devoted to measuring scenic beauty (Arthur and Boster 1976; USDA 1983). Several studies have rated esthetic qualities of forest landscapes and tested public preferences. The Scenic Beauty Estimation (SBE) technique (Daniel and Boster 1976) was developed and extensively tested on timber harvest areas in the Southwest, and was later used in the Northern Rocky Mountain area to compare viewer perceptions of different harvest and logging methods (Benson and Ullrich 1981). These studies dealt primarily with areas subjected to different logging practices, as seen in the near view (one-fourth mile distance or less). None of these studies, however, were designed to evaluate viewer preferences for areas planned to meet specific visual quality objectives.

The purpose of this study was to evaluate the attainment of visual quality objectives (VQO) and the scenic beauty ratings for a timber harvest area. This process involved several phases: identify timber harvest sites and the visual quality objective planned, determine if this objective was actually accomplished, and measure landscape architects' preferences for these areas. The extent to which landscape architects actually reflect the public's notions is reported in a separate study of the public viewer group preference ratings for the same areas (McCool and others in press).

The harvest areas included are on National Forest lands in the Northern Rocky Mountains of western Montana and northern Idaho, where timber harvest and accompanying access roads are a common management activity that affects the visual resource. The study areas represent the most common type of harvested land—mature conifer timber growing on moderate to steep terrain at middle elevations (approximately 4,000 to 7,000 ft).

Three groups of Forest Service landscape architects (LA's) were included in the evaluations—Region 1 (Northern Region), Region 4 (Intermountain Region), and Region 5 (Pacific Southwest Region). This provided an opportunity to examine if LA's from areas with different vegetation and topographic features would give similar evaluations. Five VQO's were included: Preservation, Retention, Partial Retention, Modification, and Maximum Modification (these are defined and discussed in more detail under Study Methods). The specific objectives of the study were to determine:

1. If the VQO's planned for harvest areas were achieved, based on landscape architects' judgments of color slides of the areas, and if these judgments were different among Regions.
2. Preferences of landscape architects (on a like-dislike basis) for harvest areas in different VQO's, and if these preferences differed among Regions.

STUDY METHODS

The study in general used the Scenic Beauty Estimation (SBE) method; color slides were taken of harvest areas in different VQO categories. Landscape architects rated the slides on a 9–0 (like-dislike) scale from which the SBE rating was derived. In addition, the landscape architects were asked to classify each slide as to which VQO it represented; that is, was accomplished. The five VQO categories used were selected from USDA Handbook 462 (1974):

Preservation (P) = Only ecological changes permitted

Retention (R) = Management activities not visually evident

Partial Retention (PR) = Management activities remain visually subordinate

Modification (M) = Management activities may dominate, but must borrow from natural landscape forms

Maximum Modification (MM) = Activities may dominate and may be out of scale in middle or foreground, but appear natural when seen as background.

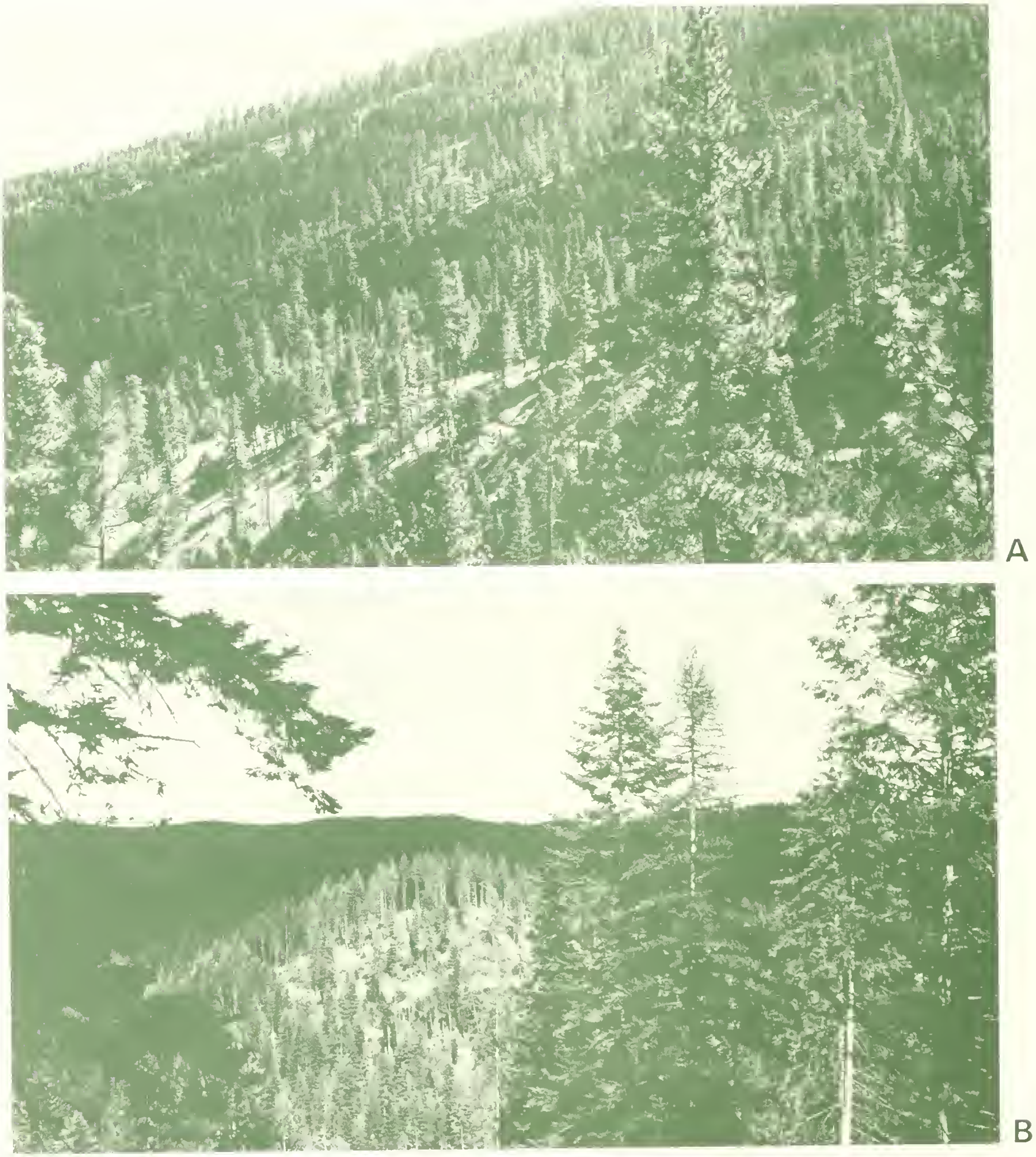

Figure 1.—Typical scenes from harvested areas: (a) Retention, (b) Partial Retention, (c) Modification, (d) Maximum Modification.

These categories are the principal ones related to most timber-growing areas and in the order listed represent increasing evidence of management activity. Normally, preservation is not a VQO used in timber-growing areas, but in this study scenes of uncut forest land were included so as to provide a baseline against which harvested areas could be compared. Typical scenes from sample areas are shown in figure 1.

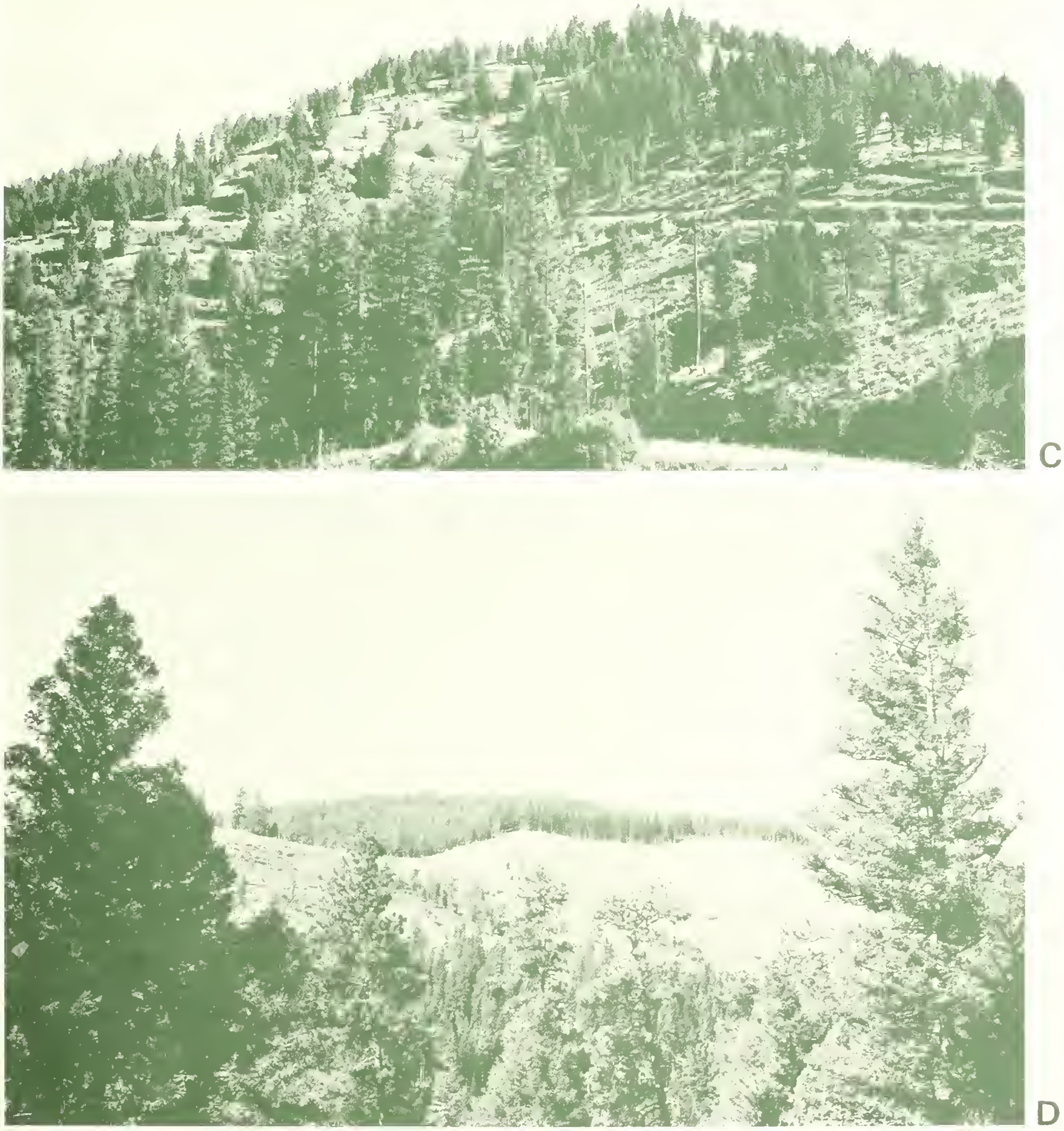

Figure 1.—(Con.)

A total of 25 sample areas were randomly sampled (five from each VQO as designated in the sale plan) from Northern Region Forest Service timber sales completed during the period approximately 1975—80. Most of the timber sales in the Region prepared during this time had landscape architect input. The 25 areas were distributed among western Montana and northern Idaho National Forests approximately in proportion to timber sale volume during the period. Sample areas were drawn from timber sale folders on file at the Forest Supervisors' offices. Several alternate sample sales were also included to cover such contingencies as poor photo conditions or ground conditions that did not correspond to site folder descriptions (such as major changes in sale layout, work not completed, etc.). Color slide photos were taken during the summer of 1982.

A final selection was made of the color slides to be used in the study. Photos of poorer quality were eliminated, and a random sample of five photos of the remainder was selected from each area. The slides were arranged in random order in the slide tray. The entire slide set then consisted of 125 slides (five VQO's × five areas in each VQO × five slides of each area). Five slides were determined to be an adequate representation of each area based on SBE procedures and testing of data from previous studies.

National Forest landscape architects from the three Regions first rated the slides on the 9—0 rating scale, and later classified the same slides as to the VQO they judged was represented. The second viewing was conducted after a break of several hours. Separate rating sessions for each group were held in conjunction with regional meetings of the LA groups in San Francisco, CA; Salt Lake City, UT; and Kalispell, MT. The same slide set was used for each group. The LA's were told only that the slides were of scenes in typical timber-growing forest areas, as viewed from roadside at middle ground viewing distance (0.5 to 3 miles). Location of the areas was not revealed.

The raw preference ratings (on a 9 = "like," 0 = "dislike" scale) were transformed into an SBE value as described by Daniel and Boster (1976). The "by slide" version of the procedure was used; this combines and standardizes preference ratings for each slide across viewers within the group. From these slide ratings an SBE score is derived for each area, using one of the uncut areas as a baseline (that is, its SBE score is set at zero and the SBE's for other areas are relative to this baseline). This results in an interval-like scale that permits various statistical analyses (Hull and others 1984). The VQO that was judged to be represented by each area was measured by the frequencies of ratings (P, R, PR, etc.) given to each slide. These were then combined and converted to percentages so comparisons could be made to determine how well areas met the intended VQO. These comparisons are described in detail in the analysis section.

ANALYSIS AND RESULTS

Attainment of Visual Quality Objectives

One purpose of this study was to compare the visual quality objective planned for the area with the landscape architects' judgment of the visual quality objective attained, as depicted by the slides. If there was perfect agreement, then 100 percent of the judgments would match the planned VQO. The actual ratings are shown in figure 2. In general, the mode of the judgments corresponds to the planned VQO, but there were variations. The most obvious difference was in the uncut areas. These were often judged as R, Retention. Comments by the LA's after sessions indicate this was a matter of interpreting category standards or definitions. Preservation is defined as permitting ecological change only, and because the entire set of slides was described as being in the general timber-growing zone, some LA's felt the P category was not appropriate and assigned R rating. Many scenes were judged to meet the planned VQO, but some scenes were judged to meet either a higher or lower VQO than what was planned. Higher ratings could reflect that actual operations on the ground were more successful in reducing impacts than was anticipated, or that natural revegetation had enhanced the scene. Lower ratings could indicate a shortcoming in planning or carrying out the harvest, or a subsequent unanticipated failure such as soil movement, revegetation failure, blowdown, insects, etc. The landscape architects were asked only to rate the slides, however; and the reasons for their ratings were not examined in this study.

Figure 2 shows percentage of ratings summarized for all five areas in each planned VQO category. In addition, the percentage ratings for each individual area were used

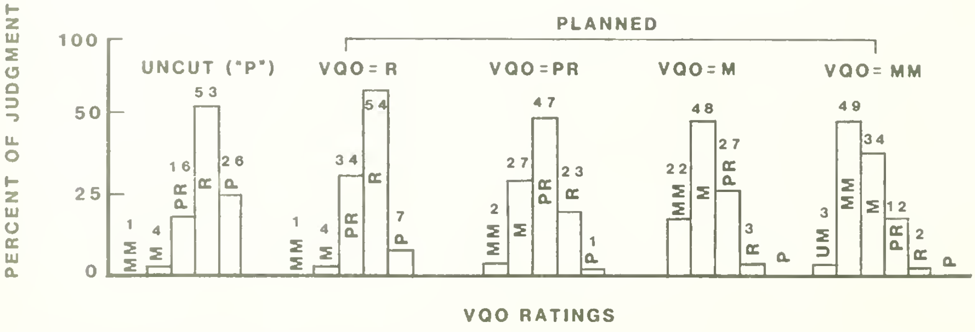

Figure 2.—Comparison of planned VQO with VQO judged to be attained.

to determine a "consensus" rating for each area. Both the median and mode of percentage ratings were considered (they were virtually identical) and the modal rating for each LA group was compared (they were nearly identical among all three groups). Each area was then classified into the VQO category achieved, based on the consensus rating. Results were as follows:

Planned VQO	Number of areas	Changes in "consensus" classification	Number of areas in "consensus" class
Uncut (P)	5	One area classed PR	4
R	5	One area classed PR	5
PR	5	One area classed R	6
M	5	No changes	6
MM	5	One area classed M	4
Total	25		25

This shows that of the 25 areas, two were classed lower than the planned VQO (one uncut and one R went to PR) and two were rated higher (one PR went to R, and one MM to M). As noted earlier, both uncut and R areas were generally classed as R (fig. 2). However, although percentage R ratings were about equal, there were distinct differences in other ratings as follows:

four uncut areas: P = 33%; R = 54%; other = 13%
five R rated areas: P = 7%; R = 59%; other = 34%

We used these differences as a basis for assigning the areas into the consensus groups of four uncut P and five R areas.

Results suggest high but not perfect matching of planned vs. attained VQO goals in the study areas. Of the 25 areas, the LA's concluded that two did not meet the intended VQO, and two exceeded the planned VQO.

Scenic Beauty Estimates

The scenic beauty estimates of landscape architects were measured on a 9—0, like-dislike scale and transformed into SBE scores. The SBE scores were summarized in two ways: with areas grouped by "planned" VQO and areas grouped by "consensus" as described above. The SBE scores for each area were then used in a threeway analysis of variance test for differences between Regions, VQO's, and type of grouping. As shown in table 1, the type of grouping (planned vs. consensus) did not affect the SBE scores, but both Region and VQO category were highly significant. None of the interactions were statistically significant, but the F-value for VQO × Region (1.356) indicates a level of interaction that may be of some practical interest (Snedecor and Cochran 1967). The actual SBE scores based on the "planned" VQO groupings are shown in table 2.

Because SBE scores measure preferences in relation to a base reference area (in this case, one of the uncut

Table 1.—Three-way ANOVA Scenic Beauty Estimation (SBE) ratings

Source	df	MS	F	Significance
Type[1]	1	140.719	0.172	0.679
VQO	4	82,555.020	100.977	.000
Region	2	11,722.107	14.338	.000
Type × VQO	4	462.223	.565	.688
Type × Region	2	.738	.001	.999
VQO × Region	8	1,108.322	1.356	.223
Type × VQO × Region	8	22.326	.027	1.0
Error	120	817.563	—	—
Total	149	—	—	—

[1] "Type" is consensus vs. planned.

Table 2.—Scenic Beauty Estimate (SBE) scores by planned visual quality objective (VQO) and landscape architect Region[1]

Region	Uncut	Retention	Partial retention	Modification	Maximum modification	Mean
4	42.8	41.6	20.0	-30.0	-86.6	-2.4
1	18.2	2.0	.4	-34.2	-87.6	-20.2
5	20.8	5.2	-10.2	-52.6	-127.8	-32.9
Mean	27.3	16.3	3.4	-38.9	-100.7	

[1] Solid line connects mean scores that are not significantly different, for all groups combined. Dashed line connects mean scores that are not significantly different within each LA group analyzed separately.

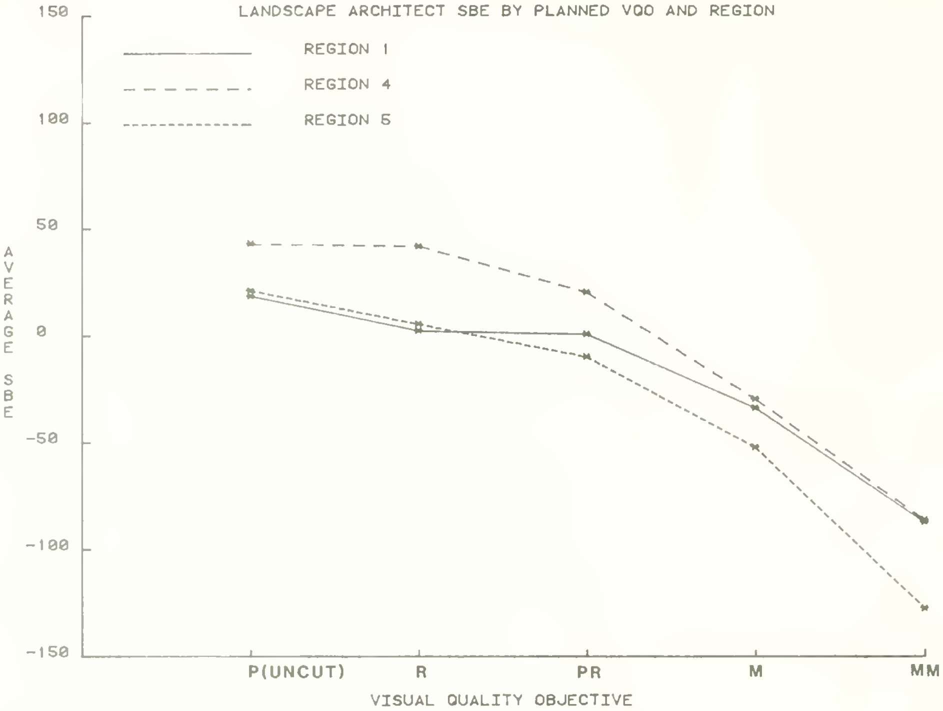

Figure 3.—Average SBE score by planned VQO category and landscape architect region.

areas), some of the scores in table 2 are positive, indicating they are preferred over the base area, and others are negative, suggesting they are viewed as less scenically attractive than the base area. The data in table 2 show that the overall order of mean SBE's is from highest in the uncut (P) areas to lowest in the Maximum Modification areas, which is the intuitive hypothesis. Not all of these scores are significantly different. Using the Newman-Keuls procedure to test for differences among all possible pairs of VQO means, the results are shown in the bottom line (mean-combined) of table 2. Maximum modification is significantly different from all other VQO's, but there is overlap among some other VQO's.

The SBE scores by Region are plotted in figure 3. The scores indicate that Region 4 and Region 5 LA's rate different VQO's similarly, but R−4 LA's consistently rate all VQO's higher than R−5 LA's do. Region 1 LA's, however, rated uncut and R VQO's about the same as R−5 LA's, but M and MM about the same as R−4 LA's. This pattern of scores among different Regions suggests the practicality of comparing SBE scores Region-by-Region (even though the F-value for the VQO × Region interaction was not statistically significant). For purposes of examining the differences between Regions, the Newman-Keuls procedure was used again to test differences between scores for each Region taken separately. The results are shown in table 2 with dashed underlining. Every Region significantly distinguished MM from all other VQO's, but the pattern of overlap among other VQO's was somewhat different among Regions.

CONCLUSIONS

Color slides from a sample of 25 timber harvest areas representing five planned VQO's in Northern Rocky Mountain National Forests were rated by Forest Service landscape architects from three Regions, on two scales—(1) the visual quality objective they judged had been attained, and (2) their scenic beauty on a like-dislike scale. Ratings indicated there were differences between the VQO planned and what was actually attained, but the consensus was that most areas met the planned VQO. (These judgments were essentially identical among all three LA groups.) In their SBE score preference ratings, however, sharp distinctions were made only for the VQO with the most evidence of activity (Modification and Maximum Modification). Among the other VQO categories, the SBE ratings were similar. The general relationship between VQO's was as expected, with higher SBE scores associated with VQO's having less evidence of activity, but statistically some scores overlapped; that is, they were not all significantly different.

The results support the idea of a system of visual quality objectives based on the degree of acceptable landscape modification. The landscape architects did express a decreasing order of preference from Preservation to Maximum Modification. The fact that there were not statistically significant differences in the scores among all VQO's may be due in part to inherent scenic variability even within a given VQO. This could account for an overlap in ratings. Also, even though differences in VQO categories were recognized, areas may have been considered as being similar in scenic beauty preference because the job had been done well and the VQO met. Further evaluations may help in addressing this question.

These results indicate that although there was some variation in achieving VQO and in preferences for VQO's, the visual management criteria and guidelines can reduce the visual impact of harvesting, particularly in the more restrictive VQO categories. This supports the rationale behind ordered VQO categories. How do these categories relate to preferences of the general viewing public? Can the public discriminate among the VQO's in order of scenic preference? The answers to these questions also have important implications for the visual management system and should be addressed in further research.

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Benson, Robert E.; McCool, Stephen F.; Schlieter, Joyce A. Attaining visual quality objectives in timber harvest areas—landscape architects' evaluation. Research Paper INT-348. Ogden, UT: Intermountain Research Station; 1985. 7 p.

Three groups of Forest Service landscape architects rated color slides of 25 timber-harvested areas for attainment of visual quality objectives and for scenic beauty. Consensus was that objectives were usually attained; beauty ratings generally dropped and distinctions became more pronounced with increasing evidence of disturbance.

KEYWORDS: esthetics, landscapes, timber harvesting, visual management

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United States
Department of
Agriculture

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**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-349

September 1985

Release of a Thinned Budworm-Infested Douglas-Fir/ Ponderosa Pine Stand

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RESEARCH SUMMARY

Current and past defoliation by western spruce budworm (*Choristoneura occidentalis* Freeman) in an 80-year-old predominantly Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) stand thinned to 14 by 14 feet was significantly lower than in a nearby untreated stand of similar age, species, and site conditions. Analysis of periodic radial growth ratios indicated that prior to thinning, Douglas-fir had been heavily defoliated by budworm and growth was seriously depressed. Following thinning, the host leave trees developed dense crowns and 10-year radial growth increased an average of 57 percent; meanwhile, radial growth of nonhost ponderosa pine (*Pinus ponderosa* Dougl.) increased 38 percent. Several hypotheses individually or collectively may explain this effect of thinning on budworm defoliation. The thinning may have caused increased mortality of budworm larval stages, the trees simply released and outgrew the insect, or the defensive chemistry of leave trees was enhanced. Radial growth of ponderosa pine accelerated in both the thinned and unthinned stands prior to thinning. This prethinning release of pine probably was in response to the defoliation, and reduced competition, of Douglas-fir.

ACKNOWLEDGMENTS

This research was done jointly between the Intermountain Research Station and the University of Montana Mission Oriented Research Program through Cooperative Agreement Supplement No. 22-C-3-INT-130.

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Release of a Thinned Budworm-Infested Douglas-fir/Ponderosa Pine Stand

Clinton E. Carlson
Robert D. Pfister
Leon J. Theroux
Carl E. Fiedler

INTRODUCTION

Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) forests of the Northern Rocky Mountains are vulnerable to the western spruce budworm, *Choristoneura occidentalis* Freeman, (Johnson and Denton 1975). Certain site and stand factors, such as stand density, are hypothesized to influence vulnerability (Carlson and others in press). While studying densities of mixed conifer stands in western Montana, we noted striking contrasts in defoliation between two adjacent stands; these stands were within an active budworm outbreak. Douglas-fir in one stand, thinned about 10 years previously, looked relatively healthy, whereas firs in the nearby unthinned stand were heavily defoliated. Substantial reduction of radial growth of host trees usually is associated with outbreaks of budworm (Williams 1966; Johnson and Denton 1975; Brubaker and Greene 1978; Alfaro and others 1982). We therefore questioned (1) whether defoliation had depressed radial stem growth of Douglas-fir before thinning and (2) whether radial growth had recovered since the thinning. This paper presents the results of a study concerning relationships of current budworm defoliation and of periodic radial increment between the thinned stand and the unthinned stand.

Western spruce budworm is a serious pest of forests in western North America (Johnson and Denton 1975; Fellin and Dewey 1982), particularly in unmanaged stands (Carlson and others in press). Although this defoliating insect does not cause significant impact in most even-aged seral conifer stands less than 20 years old, host stands older than 20 years at times are damaged (Schmidt and others 1983). Intermediate-aged (20 to 80 years) Douglas-fir/ponderosa pine (*Pinus ponderosa* Dougl.) stands have developed since the early 1900's, probably due to increasingly effective fire suppression (Dickman 1978; Arno 1980). Selective harvesting practices also contributed to the establishment and development of these stands (Schmidt and others 1983). Intermediate-age stands now occupy many thousands of acres in the Northern Rocky Mountains and appear to be highly suitable habitat for budworm.

Reducing stand density and creating unistoried conditions in immature Douglas-fir stands may decrease susceptibility to western spruce budworm (Carlson and others in press), but this hypothesis has not been extensively field tested. In unthinned natural host stands, susceptibility to western spruce budworm was found to increase as density of host species increased (Fauss and Pierce 1969; Despain 1981; Carlson and Theroux 1982). Similarly, increasing crown closure (that is, density) of balsam fir (*Abies balsamea* [L.] Mill.) in Maine resulted in better survival of spring-dispersing larvae (Kemp and Simmons 1979); in Quebec, defoliation of balsam fir increased as the basal area and number of stems of fir increased but decreased as the percentage of nonhost (hardwoods) increased (Crook and others 1979).

METHODS

Two stands, one thinned, the other unthinned, were selected for study (fig. 1) about 30 miles east of Missoula, MT, in the Blackfoot River drainage. Habitat type (Pfister and others 1977) in both stands was *Pseudotsuga menziesii/Symphoricarpos albus* h.t., with minor inclusions of *Pseudotsuga menziesii/Vaccinium caespitosum* h.t. The thinned stand (160 acres), on State land near the northern border of Lubrecht Experimental Forest, had been treated in 1973. Sixty percent of the volume removed was Douglas-fir, 35 percent ponderosa pine, and 5 percent western larch (*Larix occidentalis* Nutt.). The treatment was a best-tree thinning with removal of a few old (200+ years) veteran overstory Douglas-fir and ponderosa pine, leaving a mixed stand of dominant and codominant conifers with species composition in approximately the same proportion as the volume removed. Currently there are about 214 trees per acre, equivalent to a 14- by 14-foot spacing (table 1).

The unthinned stand (200 acres) is located about one-half mile southwest of the thinned stand on similar aspect (NW), elevation (4,000 feet m.s.l.), and slope (5 to 10 percent) as the thinned stand. The thinned stand is 77 years old, the unthinned is 86. In all respects, except for the thinning and slight age difference, the two stands are similar. The percentage of Douglas-fir and

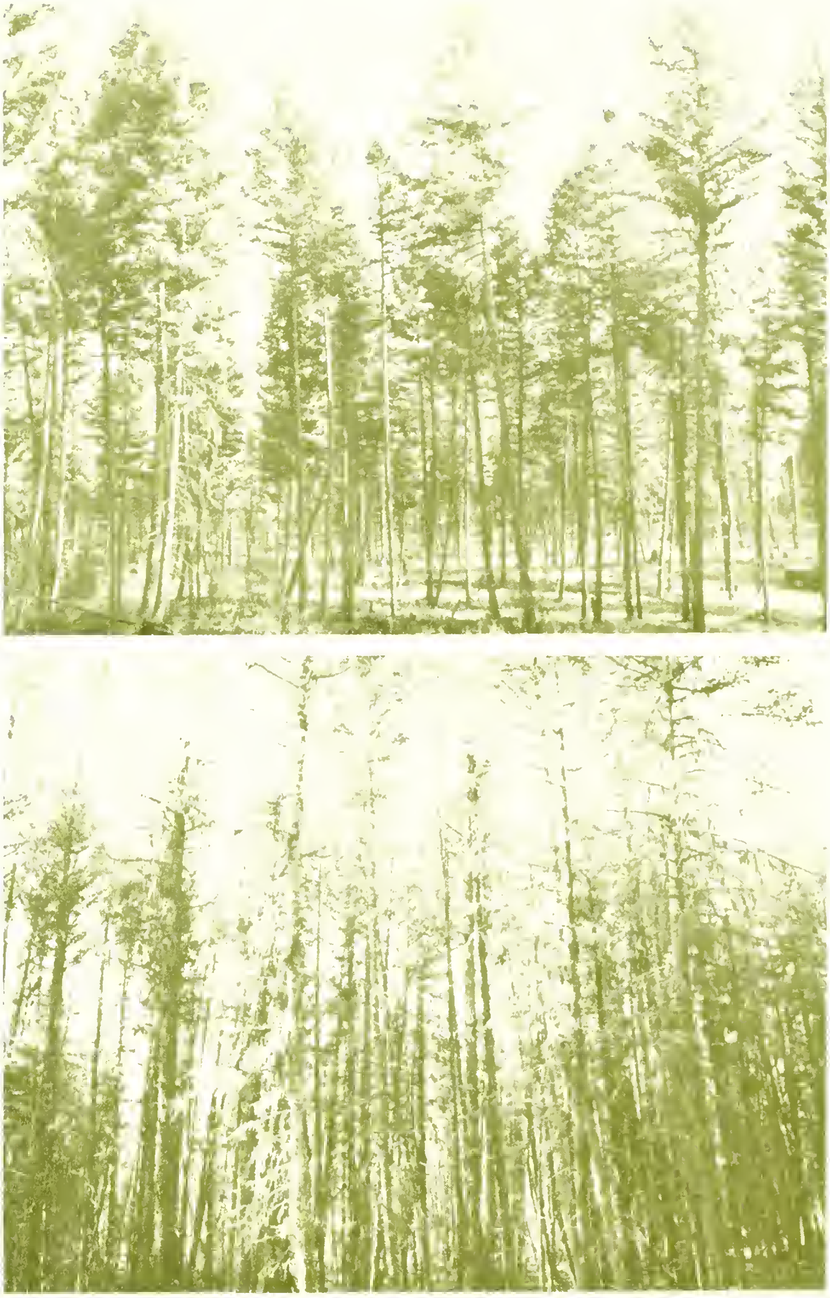

Figure 1.—Top: thinned stand thinned to 14 by 14 feet, average spacing; bottom: unthinned stand.

Table 1.—Current stand density and average diameter by species for the thinned and unthinned stands, Lubrecht Experimental Forest

Species	Basal area				Number of trees				Mean d.b.h.	
	Thinned		Unthinned		Thinned		Unthinned		Thinned	Unthinned
	Ft^2/ acre	*Pct*	*Ft^2/ acre*	*Pct*	*No./ acre*	*Pct*	*No./ acre*	*Pct*	*Inches*	
Douglas-fir	81.7	67	105.3	61	167	78	460	63	9.5	6.5
Ponderosa pine	39.7	33	67.0	39	47	22	273	37	12.5	6.7
Total	121.4		172.3		214		733			

ponderosa pine in the unthinned stand is 61 and 39, respectively, similar to the thinned stand (table 1).

Three circular 0.10-acre plots were systematically located in each stand. Within each plot in the thinned stand, tree density, species, d.b.h., height, crown ratios, and budworm defoliation were recorded. On the control plots, tree density and species composition were based on all trees present on the plot, whereas d.b.h., height, crown ratios, and defoliation were recorded for those trees that would have been retained had the plot been thinned.

A whole-crown ocular estimate, which included all crown levels and ages of foliage, of budworm defoliation was made and classed for each host tree. The classes were:

Rating class	Percent defoliation
1	0–25
2	26–50
3	51–75
4	76–100

This rating was done from the ground—no branch samples were taken.

In addition to the whole-tree estimate, current defoliation was assessed on four midcrown branches of each of three trees on each plot. Sample trees had to be climbed because the branch sampling was nondestructive (fig. 2). Four branches were permanently tagged for future reference, and defoliation on each branch was estimated and recorded according to the method of Carlson and others (1982). Twenty-five new shoots were observed and each was rated as follows:

Rating class	Percent defoliation
0	0
1	1–25
2	26–50
3	51–75
4	76–99
5	100

Classes 0 and 5 were included here because, unlike the ground-based estimates of whole-tree defoliation, it was possible to distinguish 0 and 100 percent defoliation.

Increment cores were taken to assess the response of radial stem growth to thinning, budworm defoliation, or a combination of the two. Two 0.197-inch-diameter cores were extracted at d.b.h. from opposite sides of each sample tree parallel to the topographic contour. Five sample trees of each species, Douglas-fir and ponderosa pine, were randomly selected from the list of plot trees. If five trees were not present, then the nearest tree similar to the plot trees, but outside the plot, was selected. Cores were labeled and sealed in plastic straws to prevent moisture loss, returned to the laboratory, and frozen until measurements were made.

In the laboratory, annual increment was measured to the nearest 0.003 inch and recorded for each core, using a Bannister Incremental Measuring Machine. Annual increment was averaged by year for the two cores from a sample tree and this average value was used in subsequent analyses. Our null hypotheses were:

Figure 2.—Inspecting midcrown branches for defoliation caused by budworm.

1. Defoliation (whole-tree and current-measured) on Douglas-fir was not different between the thinned and unthinned stand.
2. Radial growth of Douglas-fir (a) has not changed since thinning, (b) is not different from radial growth of ponderosa pine, and (c) is not different between the thinned and unthinned stands.

Four variables were selected to test these hypotheses, using the "t" statistic for an unpaired design (Sokal and Rohlf 1969). Whole-tree defoliation (ground-based visual estimate) and measured current defoliation (four-branch midcrown sample) on Douglas-fir were tested between stands. Two growth ratios were computed—one to represent growth since thinning, the other to depict growth prior to thinning:

Ratio 1—Radial growth since thinning ÷ 10-year radial growth just prior to thinning.

Ratio 2—10-year radial growth immediately prior to the date of thinning ÷ 10-year radial growth 11 to 20 years previous to thinning.

These radial growth ratios were tested (1) between treatments (thinned and unthinned) by species, (2) between species (Douglas-fir and ponderosa pine) by treatment, and (3) between growth periods (before and after thinning) by treatment by species.

Finally, a graphical analysis of radial increment to determine past budworm activity in the stands was done according to procedures developed previously (Carlson and McCaughey 1982).

RESULTS AND DISCUSSION

Defoliation of Douglas-fir was much lower in the thinned stand than in the unthinned stand (table 2). Whole-tree defoliation (ground-based estimate) was only 15 percent in the thinned stand, whereas the unthinned stand was 43 percent, and the difference was significant at $p < 0.05$. Similarly, measured defoliation on current-year midcrown shoots in the thinned stand was 44 percent, significantly lower ($p \leq 0.05$) than in the unthinned where defoliation averaged 66 percent.

These two different estimates of defoliation differ substantially in magnitude but are similar to each other in trend between the stands. It is not surprising that the magnitudes of the estimates are different because they estimate two different "types" of defoliation. The whole-tree estimate reflects the observer's interpretation of defoliation over all the needle age classes and crown levels in a tree, whereas the shoot counts reflect a more accurate estimate but only on current year's needles from midcrown. Thus, the whole-tree estimate likely is more appropriate for long-term evaluation because it reflects the current condition of the whole crown as influenced by several years of budworm feeding and probably closely reflects diameter growth. A detailed analysis between shoot count and ocular methods of estimating defoliation on balsam fir in eastern North America showed that plot means of ocular estimates were lower than shoot count estimates from the same trees (MacLean and Lidstone 1982), similar to our observations at Lubrecht. MacLean and Lidstone (1982) concluded that ground-based ocular methods gave reliable estimates of budworm defoliation.

Complementing this reduced defoliation in the thinned stand, radial growth of both species accelerated in response to thinning. In the unthinned stand, annual radial growth of Douglas-fir paralleled that of ponderosa pine between 1935 and 1966 (fig. 3). In 1967, however, Douglas-fir radial growth declined, presumably in response to the feeding pressure by budworm, whereas ponderosa pine increased in response to the "biological thinning" (defoliation) done by the insect.

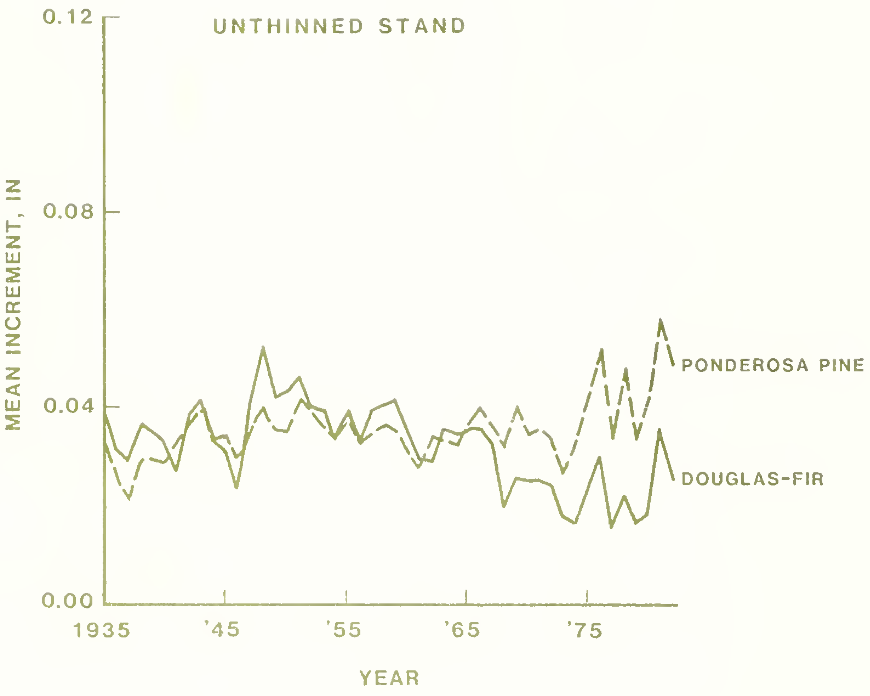

Figure 3.—Mean annual radial increment of Douglas-fir and ponderosa pine in the unthinned stand. Mean increment was similar for both species until the late 1950's when the budworm infestation became heavy.

Table 2.—Comparison of mean defoliation (percent) of Douglas-fir trees between the thinned and unthinned stands, Lubrecht Experimental Forest

Variable	Stand		Statistics	
	Thinned	Unthinned	"t"	Prob.
Whole-tree defoliation	15	43	−8.23	0
Measured current defoliation	44	66	−2.72	0.016

Radial growth of Douglas-fir was similar to that of pine in the thinned stand prior to the thinning until about 1960 (fig. 4). Radial increment of both species increased between 1935 and 1952 but decreased from 1952 to 1960. Subsequently, the trend for fir diverged from that of pine from 1960 until 1973, about the date of thinning. Radial increment of both species then increased from 1973 until present (1983). Unlike the unthinned (fig. 3), however, pine in the thinned stand (fig. 4) maintained much better annual increment (about 0.07 inch per year) than the fir (about 0.04 inch per year).

The general presence of budworm in the two stands is reflected in the radial growth of Douglas-fir as analyzed according to the methods of Carlson and McCaughey (1982). Budworm appears to have inpacted the fir about 1960, indicated by the divergence of the host curve (fir) from the nonhost (fig. 5). The cumulative curve for Douglas-fir also dropped sharply in 1927, but because the same inflection at the same date occurred for pine, that drop is attributed to factors other than budworm.

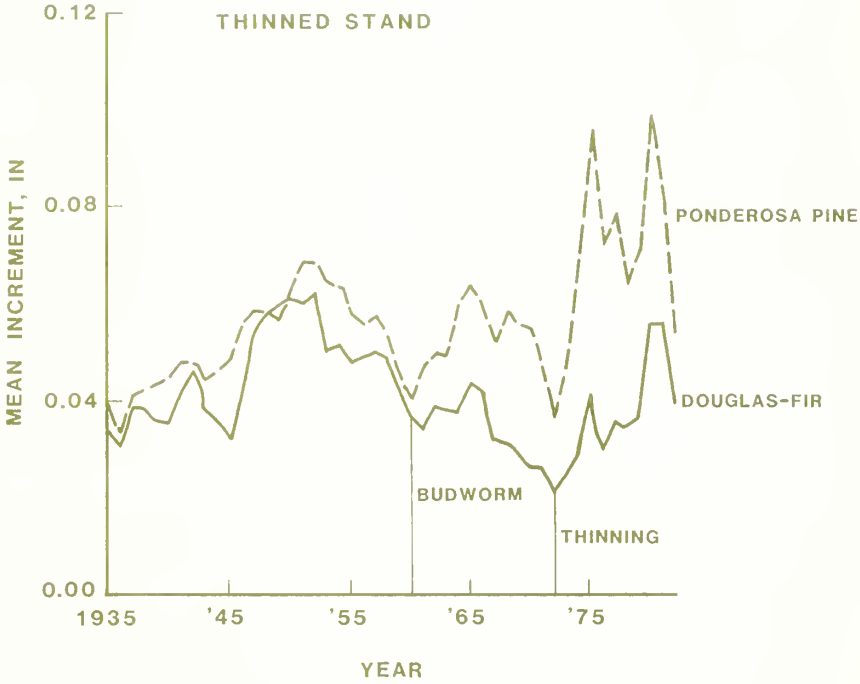

Figure 4.—Mean annual radial increment of Douglas-fir and ponderosa pine in the thinned stand. The budworm was heavy during the late 1950's through the 1970's, and the pine released in the late 1960's, presumably due to the biological thinning done by the insect on the Douglas-fir.

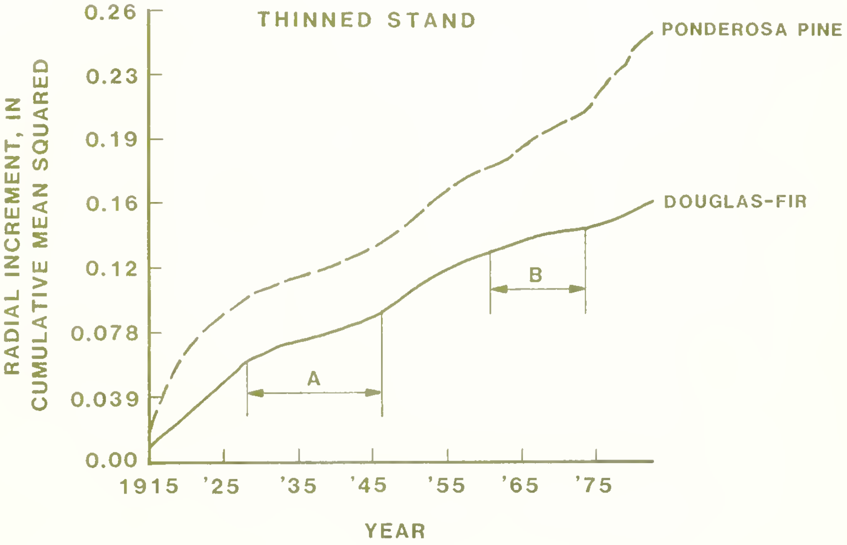

Figure 5.—Cumulative mean squared radial increment of Douglas-fir and ponderosa pine in the thinned stand. Budworm probably caused the deflection of the Douglas-fir curve from 1960 to 1973 (B), whereas other factors, such as drought and/or stand density, caused the deflection beginning in 1927 (A). A similar trend was observed for the unthinned stand.

The interpretation of a budworm-induced impact on fir between 1960 and 1983 in the unthinned stand appears to be reasonable and is corroborated by yearly observations of defoliation at Lubrecht (Fellin 1984).

The relative growth responses (growth ratios) of both Douglas-fir and ponderosa pine demonstrate the significance of the thinning and the influence of budworm (fig. 6). Current relative radial growth (ratio 1) of Douglas-fir in the thinned stand was significantly greater than in the unthinned stand ($p \leq 0.05$); ponderosa pine had a modest but nonsignificant ($p \leq 0.05$) increase (table 3). Prior to thinning (ratio 2), relative growth of Douglas-fir actually was slightly greater in the unthinned stand than in the thinned stand, but the difference was barely significant ($p \leq 0.05$), whereas ponderosa pine growth was not statistically different between the stands.

Relative radial stem growth (ratios 1 and 2) of Douglas-fir was significantly less ($p \leq 0.05$) than ponderosa pine in the unthinned stand (table 4). Relative growth of fir also was significantly less ($p \leq 0.05$) than pine in the thinned stand prior to treatment (ratio 2). Nevertheless, posttreatment relative growth (ratio 1) of fir in the thinned stand was not different from the relative growth of pine; here Douglas-fir radial growth accelerated and, in a relative sense, nearly equaled that of pine.

Both Douglas-fir and ponderosa pine responded dramatically to thinning. Radial growth rates of both species in the thinned stand after thinning (ratio 1) were significantly greater ($p \leq 0.05$) than before thinning (ratio 2) (table 5). Radial growth of Douglas-fir increased 57 percent, whereas pine increased 38 percent. In the unthinned stand, however, growth of Douglas-fir did not change between the periods (ratio 1 vs. ratio 2, $p \leq 0.05$), whereas growth of ponderosa pine increased significantly ($p \leq 0.05$) during the most recent period.

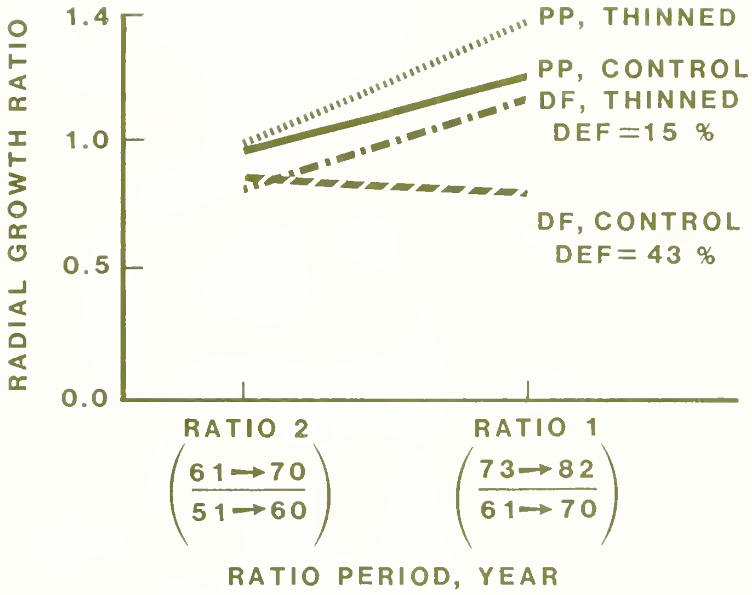

Figure 6.—Influence of thinning on radial growth of ponderosa pine and of Douglas-fir infested with western spruce budworm. Thinning relieved the budworm pressure on Douglas-fir, resulting in accelerated radial growth. The nonhost ponderosa pine exhibited accelerated radial growth before thinning and in the unthinned stand, demonstrating the "biological thinning" induced by the budworm. PP = ponderosa pine; DF = Douglas-fir; DEF = defoliation; 61 = 1961; 70 = 1970.

Table 3.—Comparison of radial growth ratios by species between the thinned and unthinned stands, Lubrecht Experimental Forest

	Thinned	Unthinned	"t"	Prob.
Ratio 1 DF	1.13	0.74	3.10	0.004
PP	1.35	1.22	1.00	.329
Ratio 2 DF	.72	.80	-2.08	.045
PP	.98	.98	0	.998

Table 4.—Comparison of radial growth ratios between species in the thinned and unthinned stands, Lubrecht Experimental Forest

	Thinned				Unthinned			
	DF[1]	PP[1]	"t"	Prob.	DF	PP	"t"	Prob.
Ratio 1	1.13	1.35	-1.49	0.146	0.74	1.22	-4.35	0
Ratio 2	.72	.98	-4.11	0	.80	.98	-3.28	0.003

[1] DF = Douglas-fir; PP = ponderosa pine.

Table 5.—Comparison of pre- and posttreatment radial growth ratios by species in the thinned and unthinned stands, Lubrecht Experimental Forest

		Ratio 2 (before thinning)	Ratio 1 (after thinning)	"t"	Prob.
Thinned stand	DF[1]	0.72	1.13	3.96	0
	PP[1]	.98	1.35	3.04	0.005
Unthinned stand	DF	.74	.80	-.88	.383
	PP	.98	1.22	2.20	.038

[1] DF = Douglas-fir; PP = ponderosa pine.

The poor periodic radial increment of Douglas-fir in the unthinned stand and in the thinned stand prior to thinning is attributed to a combination of stand density and defoliation by western spruce budworm. The insect has been present at relatively high levels (obvious defoliation on Douglas-fir) in the vicinity of the study area since the late 1950's (Fellin 1984), and we have every reason to believe that fir in the thinned stand and unthinned stand was equally affected by budworm. Without budworm, we would expect the relative growth of fir to be similar to the pine, a notion supported by the radial growth patterns between 1935 and 1960 (figs. 3, 4).

Thinning appeared to alleviate budworm pressure; defoliation was much reduced in the thinned stand and residual trees, both host and nonhost accelerated in radial stem growth. We do not know whether absolute budworm populations were reduced in the thinned stand, but we suspect so. Thinning, however, may have stimulated the crowns of the residual Douglas-fir, resulting in production of high amounts of foliage. Given a constant budworm population per tree, the **relative** budworm population per tree (budworms per unit foliage) in the thinned stand would have decreased, resulting in a lower defoliation percentage. Alternatively, opening the stand probably would increase dispersal losses of the larval stages, also resulting in lower defoliation.

Furthermore, the defensive chemistry of fir may have been enhanced by the thinning. Cates and others (1983) showed that terpene profiles of Douglas-fir are altered by stress. As moisture stress increased, bornyl acetate decreased, causing more favorable substrate for budworm. Presumably, the thinning at Lubrecht decreased tree stress, augmented the defensive chemistry, and reduced susceptibility of the Douglas-fir to western spruce budworm.

Whatever the reasons, radial growth of Douglas-fir in the thinned stand recovered and nearly equaled the thinning response of the nonhost ponderosa pine. Given that the stands are relatively old for thinning (about 80 years), this response should be encouraging to land managers because we would expect similar or better responses in younger stands.

Ponderosa pine apparently benefited from the budworm outbreak. In the unthinned stand, current 10-year periodic radial increment increased dramatically. This accelerated growth of pine in the unthinned stand indicates that the budworm was acting as a biological thinning agent. This presumed natural "thinning" effect has been observed elsewhere for western spruce budworm (Carlson and McCaughey 1982), but this study presents more definitive data supporting such an effect.

Although this study shows the influence of thinning on budworm defoliation and host tree growth, some caution is advised. This was a case study between two stands; there was no replication to include other thinned and unthinned stands. Furthermore, the sample size was small. Thus, the results may be applicable only to the stands from which the data were collected. In our opinion, however, the results are broadly applicable. Based on the literature, the biology of the budworm and its hosts, and data from this study, we conclude that thinning the 80-year-old stand reduced the pressure of budworm on Douglas-fir and significantly improved the growth of both ponderosa pine and fir. At least, this is a strong working hypothesis that should be valuable for researchers and land managers until further testing is possible.

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Eighty-year-old Douglas-fir (*Pseudotsuga menziesii*) in a thinned stand of mixed conifers in western Montana showed less impact due to defoliation by western spruce budworm (*Choristoneura occidentalis*) than firs in an adjacent unthinned stand. Radial growth of thinned fir increased 57 percent; ponderosa pine (*Pinus ponderosa*), 38 percent; whereas unthinned fir grew very slowly. In both stands, radial growth of pine increased substantially, even before thinning, probably because defoliation weakened the competing fir. Thinning may reduce budworm impact by increasing larval mortality, enhancing host tree growth, or stimulating the tree's defensive chemistry.

KEYWORDS: *Choristoneura*, budworm, silviculture, thinning, stand density, budworm impact

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United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-350

October 1985

Recreational Trampling Effects on Six Habitat Types in Western Montana

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CLEMSON UNIVERSITY
APR 10 1986
PUBLIC DOCUMENTS

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ACKNOWLEDGMENTS

I am grateful to many people for help on this project. Robert Christian, Susan Kerns, Jeffrey Marion, and Margaret Petersen endured the tedium of trampling. Margaret Petersen provided computer assistance. Peter Stickney confirmed species identifications for many of the more difficult plants. Scott Beckett dug and described the soil profiles.

RESEARCH SUMMARY

This study examined the response of six vegetation types in western Montana to experimental trampling. The types selected were representative of those most frequently used recreationally in the neighboring Bob Marshall Wilderness: the *Abies lasiocarpa/Clintonia uniflora* (subalpine fir/queencup beadlily), *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* phase (subalpine fir/queencup beadlily-dwarf huckleberry), *Abies lasiocarpa/Vaccinium caespitosum* (subalpine fir/dwarf huckleberry), *Abies lasiocarpa/Xerophyllum tenax* (subalpine fir/beargrass), *Pseudotsuga menziesii/Symphoricarpos albus* (Douglas-fir/snowberry), and *Festuca scabrella-F. idahoensis* (rough fescue-Idaho fescue) habitat types. Results are compared with findings from similar experiments in other vegetation types.

All of the forested habitat types showed a curvilinear relationship between amount of trampling and loss of vegetation cover, loss of plant species, and soil compaction. The effect of any incremental increase in amount of trampling decreases as trampling intensity increases. This indicates that trampling damage will generally be minimized when concentrated in space rather than dispersed over large areas. The *Abies lasiocarpa/Xerophyllum tenax* habitat type was the most resistant forest type studied, suggesting that it would be worthwhile encouraging campers to select sites in this type.

The grassland proved to be much more resistant to vegetation loss than any of the forested types. Here no significant cover loss occurred until after a total of 1,600 trampling passes had been administered. In such a resistant vegetation type, dispersal of use may be advantageous.

In contrast to vegetation loss and soil compaction, trampling intensities had to be very high before much bare mineral soil was exposed. The habitat with the thickest organic horizons (*Abies lasiocarpa/Clintonia uniflora*) experienced the least soil exposure. If heavy enough to kill most vegetation, use should be directed to sites with thick organic horizons.

Managers of wildernesses and other dispersed recreation areas with similar vegetation can utilize these data to estimate the effects of various use levels. It was possible, for example, to estimate the amount of use that sites in these habitat types could receive and still maintain 50 percent vegetation cover and experience mineral soil exposure of no more than 5 percent. For a party of three backpackers, these frequencies range from no use in *Abies lasiocarpa/Clintonia uniflora* to 5 to 8 nights in *Abies lasiocarpa/Xerophyllum tenax*, and 10 to 15 nights in *Festuca scabrella-F. idahoensis*. These latter two are some of the most resistant natural vegetation types ever studied; use frequencies for vegetation types studied elsewhere can be estimated, with caution, from several tables that compare the resistance of types studied here to types studied elsewhere.

The resistance of the major plant species on these sites is assessed. This information can also be used to evaluate the relative durability of alternative recreation sites.

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Recreational Trampling Effects on Six Habitat Types in Western Montana

David N. Cole

INTRODUCTION

Wilderness and similar areas, ostensibly managed to perpetuate natural ecosystems, are often compromised by recreational use. The most pronounced and obvious impact of recreational use occurs on trails and at campsites. In 1980, managers of about two-thirds of the areas in the National Wilderness Preservation System reported excessive impacts to vegetation and soil on campsites and trails (Washburne and Cole 1983).

Some of this disturbance, such as trees damaged by chopping or tying horses to them, can be eliminated through programs that educate users about minimum-impact camping. Nevertheless, much of the vegetation and soil change on trails and campsites is inevitable. Wherever trampling occurs, vegetation and soil are disturbed. The amount of change is a function of amount and frequency of trampling, type of use, season of use, and site conditions. For most areas, amount and frequency of use and site conditions are the most important of these variables and the most amenable to control by the manager attempting to limit site damage. Where use of pack and saddle stock is significant, managers must be aware that trampling by stock has much more impact than trampling by humans (Weaver and Dale 1978). Trampling is also generally more damaging when soils are water-saturated, as they often are during early season, than when they are dry (Edmond 1966; Willard and Marr 1970).

Many studies have documented the effects of trampling on backcountry trails and campsites; some of these have related amount of change to amount of use and site conditions (Cole and Schreiner 1981). The most effective approach for isolating the effect of these two variables on amount of impact is through experimental application of controlled amounts of trampling on previously undisturbed sites. This approach has been adopted in a number of studies and is the approach taken in the study reported here.

To truly simulate the trampling pressure placed on recreation sites, controlled trampling needs to be applied for a number of years until a new equilibrium between ongoing trampling and vegetation/soil conditions can be established. Unfortunately, in all but one of the experimental studies conducted so far—one by Schreiner (1980)—trampling has been applied for only 1 year. This limits conclusions to initial deterioration; no conclusions about long-term deterioration are possible. To provide a better understanding of these long-term processes, I initiated a study in which trampling is being applied year after year until conditions have a chance to equilibrate (that is, until year-to-year change in vegetation and soil conditions becomes minimal).

Nevertheless, because past studies have applied trampling for only one season, and because little attempt has been made to integrate the results of these studies, it seemed worthwhile to report the initial results of this study (after one season of trampling) and interpret them in light of earlier comparable work. The objectives of this paper, then, are to (1) review and integrate the results of previous single-season studies of trampling and (2) describe the effects of one season of experimental trampling on six vegetation types in western Montana.

PREVIOUS STUDIES

The results of about 30 experimental trampling studies have been published. Most of these have been concerned primarily with vegetation change, although a few have focused on changes in soil condition and increases in runoff and erosion.

It is difficult to generalize from these results about the relationship between amount of trampling and impact for two reasons. First, a wide variety of vegetation types throughout Europe and North America have been examined, and the effects of trampling are different for each type. This does, however, allow comparisons of the relative resistance of different vegetation types and permits us to gain some insight into what species, growth forms, soil conditions, and so on, tolerate trampling better than others.

The second (and more important) reason is the lack of uniformity in methods. Some of the more important differences include:

1. **Amount of trampling.**—The number of trampling passes administered varies greatly. Comparability can usually be achieved by interpolating or cautiously extrapolating results.
2. **Characteristics of tramplers.**—The type of footwear and weight of the tramplers vary, influencing both the amount and nature of the stresses applied. In several cases the effects of different types of footwear have been carefully examined; in general, the effects of different types of footwear have been similar (Saunders and others 1980; Kuss 1983). Others have argued that because recreationists vary in weight and use a variety of footwear types, simulated trampling should also incorporate this variability.
3. **Trampling method.**—A few studies have used artificial "trampling machines"; in one study (Hartley 1976) a person systematically trampled until the entire sample area was trampled uniformly once; and in another, trampling stress was calculated in terms of "standard steps" (Holmes and Dobson 1976). These studies provide some insights, particularly into the resistance of certain vegetation types, but cannot be directly compared with the

vast majority of studies in which tramplers walked along each treatment lane, using a natural gait, for a predetermined number of passes.

4. **Sampling procedures.**—Most treatment lanes are sampled and the size of the sampling unit varies. Because trampling stress is most highly concentrated in the center of each lane, narrow sampling units in the center of the lane will experience more overall trampling stress than a wider unit that includes some of the less-trampled edge of the lane.

5. **Timing of trampling.**—Some studies spread the trampling over a season, while others apply all of the trampling at once. Some have examined the importance of the period of time over which trampling occurs by comparing the effects of the same number of passes applied either all at once or spread over the season. Such a comparison is difficult to interpret because (1) the effect of one-time trampling varies with the time of year the trampling is applied, and (2) in many cases the period of time between trampling application and measurement has varied, so more recovery is possible in some cases than in others.

6. **Basis of comparison.**—Several studies have not measured the pretrampling condition of treatment lanes.

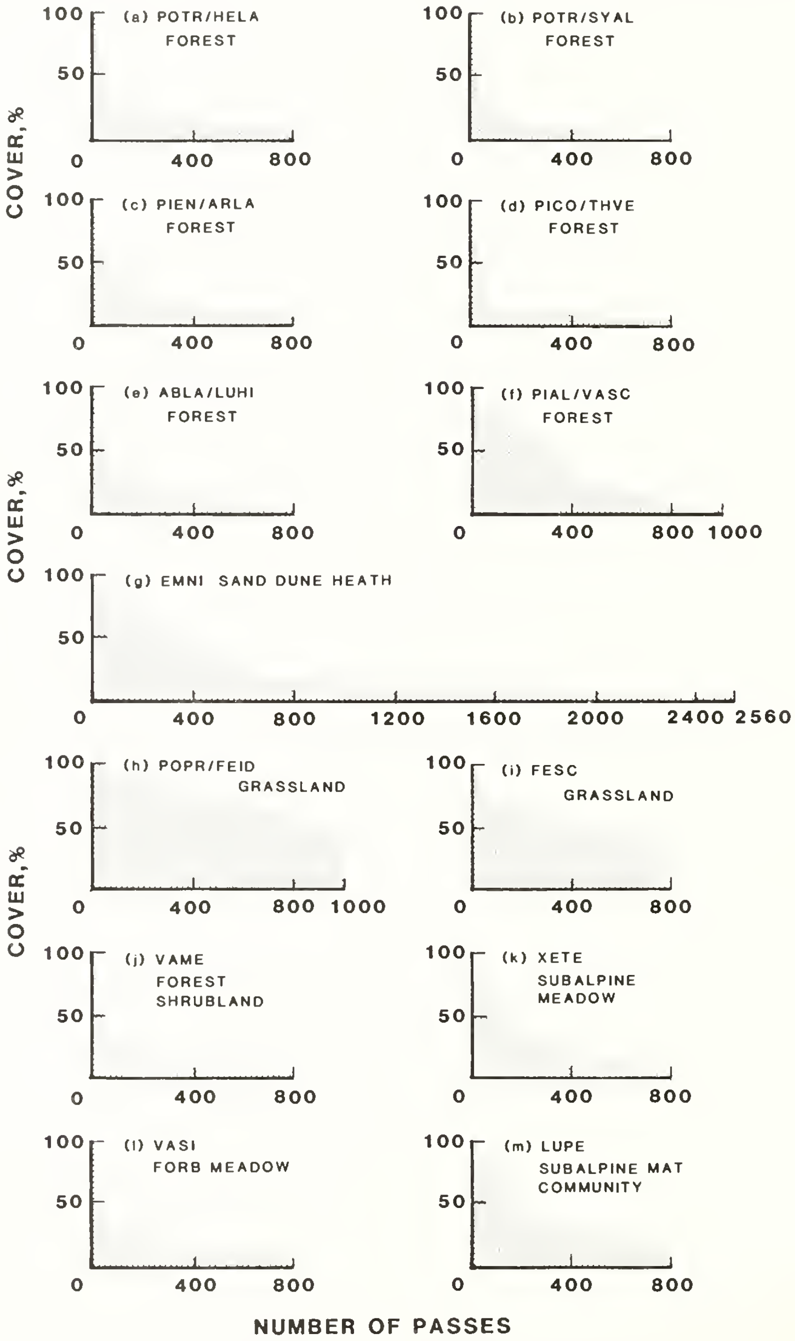


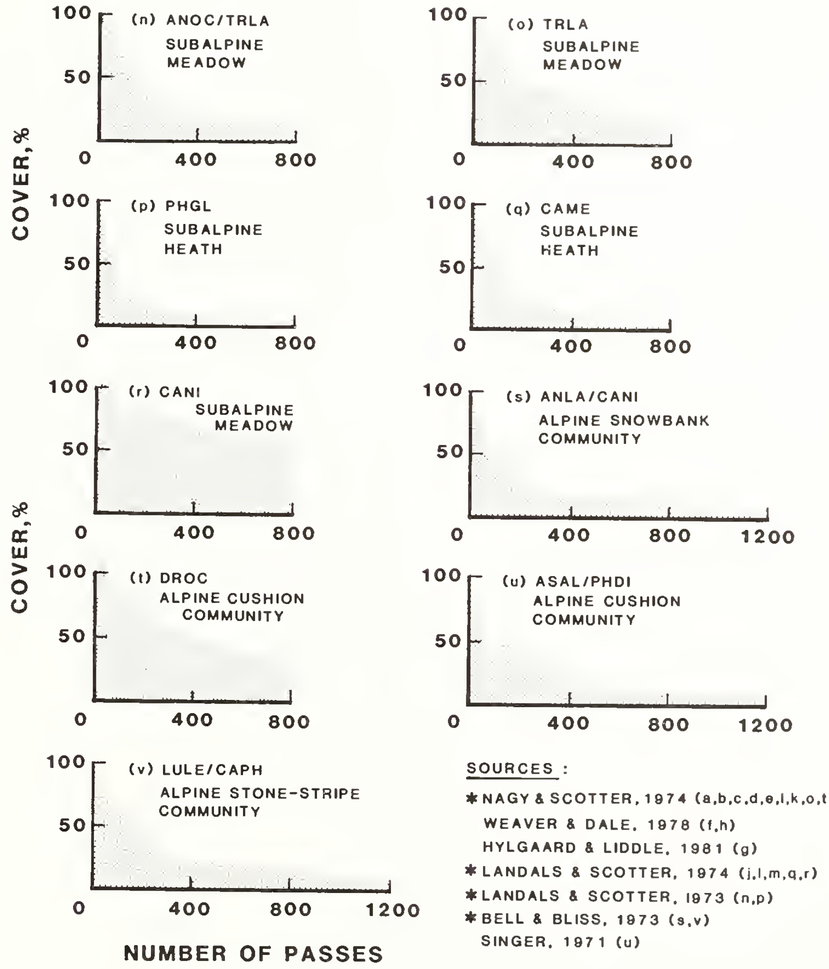
Figure 1.—The relationship between vegetation cover (see text for definitions of relative and estimated relative cover) and amount of trampling (number of passes) for previously studied vegetation types. An asterisk by the source indicates that relative cover was estimated (refer to text for definitions).

Instead, they rely on a control lane as an estimate of pretrampling conditions. Most plant communities are so heterogeneous that this introduces significant loss of precision. The preferred design, used in many studies, utilizes control and treatment lanes and includes pre- and posttreatment measurements on each.

The implications of these variations in study design need to constantly be kept in mind. Nevertheless, many studies are directly comparable and with others some generalization is possible. Questions that can be partially answered at this time are: (1) What is the nature of the relationship between amount of trampling and vegetation and soil disturbance? (2) Which plant community types and growth forms are more resistant to damage than others? (3) How does the timing and frequency of trampling affect amount of disturbance?

Relation Between Amount of Trampling and Amount of Vegetation Loss

All studies show that increased trampling leads to a general increase in cover loss; however, for each plant community the curve that describes this relationship varies in shape. Figure 1 presents curves relating surviving cover to number of passes for the 22 plant communities where this relationship can be described. In some of these, the dependent variable is "relative cover," defined as the percentage of original cover remaining after trampling, adjusted for any changes that occurred on control



Key to Species Abbreviations:

ABLA = Abies lasiocarpa
ANOC = Anemone occidentalis
ANLA = Antennaria lanata
ARLA = Arnica latifolia
ASAL = Aster alpigenus
CANI = Carex nigricans
CAPH = Carex phaeocephala
CAME = Cassiope mertensiana
DROC = Dryas octopetala
EMNI = Empetrum nigrum
FEID = Festuca idahoensis
FESC = Festuca scabrella
HELA = Heracleum lanatum
LUPE = Luetkea pectinata
LULE = Lupinus lepidus
LUHI = Luzula hitchcockii
PHDI = Phlox diffusa
PHGL = Phyllodoce glanduliflora
PIEN = Picea engelmannii
PIAL = Pinus albicaulis
PICO = Pinus contorta
POPR = Poa pratensis
POTR = Populus tremuloides
SYAL = Symphoricarpos albus
THVE = Thalictrum venulosum
TRLA = Trollius laxus
VAME = Vaccinium membranaceum
VASC = Vaccinium scoparium
VASI = Valeriana sitchensis
XETE = Xerophyllum tenax

Figure 1.—(con.)

lanes (Bayfield 1979). What I have called "estimated relative cover" is a less precise measure of change; in this case, original cover was not reported, so estimated relative cover is the surviving cover on the trampled lane expressed as a percentage of cover on the control lane. To be as accurate as relative cover, the original cover on controls and all trampled lanes would have to be identical. Although this is unlikely to be the case, differences are seldom substantial enough to create a large problem. For some studies, I reanalyzed original data to convert them to these two consistently defined variables. They are generally arranged from forested to nonforested communities and, within these classes, from low to high elevation.

Almost without exception, these graphs illustrate the curvilinear relationship between amount of use and amount of vegetation loss. Vegetation is lost most rapidly following the initial application of trampling; successive incremental increases in amount of trampling have progressively less effect on vegetation cover. This corroborates the conclusions of several studies of the relationship between use and impact on existing trails and campsites (for example, Dale and Weaver 1974; Cole and Fichtler 1983). Only the most resistant of these vegetation types, the *Poa pratensis-Festuca idahoensis* grassland, does not lose cover most rapidly at low levels of trampling.

Relative Resistance of Different Plant Community Types

Of the many potential means available for evaluating the resistance of different plant communities, three seem particularly useful:

1. Liddle (1975a) suggested evaluating resistance on the basis of the number of passes required to reduce cover to 50 percent of its original value. This provides a useful index of how rapidly cover is lost after the introduction of trampling. Such an index does not, however, indicate how well a community type will stand up to either prolonged or heavy amounts of trampling.
2. Although none of these 1-year studies can be used to estimate the effects of prolonged trampling, most studies report the effects of at least 800 passes. Therefore relative cover after 800 passes can be used as an index for resistance to heavy trampling.
3. The most useful index would reflect resistance to a broad range of trampling intensities. The curves in figure 1 can be used to provide such an index. To facilitate comparison, an index was calculated that expressed the area under each curve (up to 800 passes) as a percentage of the entire graphed area. In effect, this integrates the effects of trampling across the range from 0 to 800 passes, expressing surviving cover as a mean percentage of control conditions. Table 1 categorizes 32 plant communities on the basis of these three alternative indices.

Several conclusions can be drawn from table 1. First, the relative resistance of a community type to heavy trampling is similar to its resistance to light trampling. Although some changes in order exist (for example, ericaceous undergrowth is usually more sensitive to heavy than to light trampling), the rankings based on these three indices of resistance are generally similar. Thus, any single index (such as the number of passes it takes to reduce cover to 50 percent of its original value) can be used as a rough index of initial resistance. It is important to remember that resistance to prolonged trampling and ability to recover are not reflected in any of these indices.

Second, there is little relationship between elevational zone and resistance. Alpine communities, even within the same general area, range from very susceptible (*Phyllodoce glanduliflora*) to very resistant (*Carex nigricans*); the same is true of low elevation types.

Third, most of the very resistant types are dominated by grasses, sedges, and rushes. But not all grasslands are highly resistant. Some have only a moderate level of resistance, and the sedge marsh (type 6) is one of the least resistant vegetation types. This resistance gradient may reflect, in part, the abundance of moisture. As mentioned, the initial effects of trampling are generally most profound on moist sites and the sedge marsh is inundated by water for much of the year (Nagy and Scotter 1974).

Finally, with one exception, the forested sites examined are quite susceptible to trampling damage. Most of these forests occupy mesic sites and have a ground cover dominated by lush forbs. The whitebark pine forest, with a ground cover dominated by the ericaceous shrub *Vaccinium scoparium* (grouse whortleberry), is considerably more resistant. Some of this apparent resistance may be a result of study method. In this study, trampling treatments and measurements were completed all at once. *Vaccinium* spp. often die slowly after trampling (Bayfield 1979), so by immediately measuring survival, cover loss of *Vaccinium scoparium* may have been underestimated. In studies of existing recreation sites, most researchers have found *Vaccinium scoparium* to be a fragile ground cover (see, for example, Dale and Weaver 1974; Cole 1982a,b).

Relative Resistance of Different Growth Forms

Morphological characteristics of plants that influence resistance to trampling include location, size, erectness and strength of leaves, strength of petioles and nodes, woodiness and erectness of stems, extent and type of root system, and bud location. Characteristics found to be common to resistant species in experimental studies are short, procumbent, and/or flexible stems (Schreiner 1974), a low-growing, matted or tufted growth form (Singer 1971; Holmes and Dobson 1976), basal leaves (Holmes and Dobson 1976; Rogova 1976), and leaves that are pliable, folded, and either thick or narrow and wiry (Schreiner 1974; Holmes and Dobson 1976). Particularly fragile plants usually have tall, caulescent (obviously leafy), succulent stems and thin leaves, or brittle, low-growing woody stems and branches (Singer 1971; Holmes and Dobson 1976; Rogova 1976).

Studies of campsites and trails have consistently found graminoids (grasses and grasslike plants) to be particularly resistant to trampling (see, for example, Cole 1982a). This has also been confirmed in experimental studies (Wagar 1964; Nagy and Scotter 1974; Schreiner 1980). Forbs and shrubs are more variable in

Table 1.—Relative resistance of plant community types to trampling damage

	Resistance to:		
Plant community types[1]	Light[2] trampling	Heavy[3] trampling	Both[4]
1. *Pinus contorta/Thalictrum venulosum* (lodgepole pine forest)	VS	VS	VS
2. *Populus tremuloides/Heracleum lanatum* (aspen forest)	VS	SS	VS
3. *Populus tremuloides/Symphoricarpos albus* (aspen forest)	VS	SS	VS
4. *Vaccinium membranaceum* (subalpine huckleberry shrubland)	SS	VS	VS
5. *Phyllodoce glanduliflora* (subalpine heath)	SS	VS	VS
6. *Carex rostrata-C. aquatilis* (sedge marsh)	VS	SS	—
7. *Cassiope mertensiana* (subalpine heath)	SS	VS	SS
8. *Abies lasiocarpa/Luzula hitchcockii* (subalpine fir forest)	SS	SS	SS
9. *Aster alpigenus-Phlox diffusa* (alpine cushion community)	SS	SS	SS
10. *Picea engelmannii/Arnica latifolia* (Engelmann spruce forest)	SS	N	SS
11. *Valeriana sitchensis* (subalpine forb meadow)	SS	N	SS
12. *Picea lauca/Vaccinium uliginosum* (boreal spruce forest)	SS	—	—
13. *Antennaria lanata-Carex nigricans* (alpine snowbank community)	SS	N	N
14. *Holcus lanatus-Agrostis stoloniferus* (acid grassland)	N	SS	—
15. *Deschampsia flexuosa-Holcus lanatus* (acid grassland)	N	SS	—
16. *Xerophyllum tenax* (subalpine beargrass meadow)	N	SS	N
17. *Lupinus lepidus-Carex phaeocephala* (alpine stone-stripe community)	N	N	N
18. *Anemone occidentalis-Trollius laxus* (subalpine forb meadow)	N	N	N
19. *Antennaria lanata-Hieracium gracile* (subalpine forb meadow)	N	—	—
20. *Phlox diffusa-Carex phaeocephala* (subalpine cushion community)	N	—	—
21. *Empetrum nigrum* (sand dune heath)	N	N	SR
22. *Arrhenatherum elatius-Holcus lanatus* (neutral grassland)	N	SR	—
23. *Trollius laxus-Aster foliaceus* (subalpine forb meadow)	N	SR	SR
24. *Luetkea pectinata* (subalpine mat plant community)	N	SR	SR
25. *Calluna vulgaris-Deschampsia flexuosa* (heath-grassland)	SR	N	—
26. *Pinus albicaulis/Vaccinium scoparium* (whitebark pine forest)	SR	N	SR
27. *Arctostaphylos uva-ursi-Carex eburnea* (heath-grassland)	SR	—	—
28. *Dryas octopetala* (alpine cushion community)	SR	SR	VR
29. *Aster alpigenus-Festuca idahoensis* (subalpine meadow)	VR	—	—
30. *Festuca scabrella-Danthonia intermedia* (prairie grassland)	VR	VR	VR
31. *Poa pratensis-Festuca idahoensis* (grassland)	VR	VR	VR
32. *Carex nigricans* (subalpine sedge meadow)	VR	VR	VR

[1] Sources are as follows: Nagy and Scotter 1974 (1,2,3,6,8,10,16,23,28,30); Landals and Scotter 1974 (4,7,11,24,32); Landals and Scotter 1973 (5,18); Singer 1971 (9); Schreiner 1980 (12); Bell and Bliss 1973 (13,17); Harrison 1981 (14,15,22,25); Schreiner 1974 (19,20,29); Hylgaard and Liddle 1981 (21); Weaver and Dale 1978 (26,31); Bowles and Maun 1982 (27).

[2] The index for resistance to light trampling is the number of passes required to reduce cover to 50 percent of original conditions. Classes are as follows: very susceptible (VS) (0—25 passes); somewhat susceptible (SS) (26 to 100 passes); neither susceptible nor resistant (N) (101 to 250 passes); somewhat resistant (SR) (251 to 500 passes); very resistant (VR) (more than 500 passes).

[3] The index for resistance to heavy trampling is relative or estimated relative cover after 800 passes. Classes are as follows: VS (0 to 3 percent); SS (4 to 7 percent); N (8 to 15 percent); SR (16 to 35 percent); VR (more than 35 percent).

[4] The index for both is the percentage of area under the curves in figure 1—essentially the mean relative or estimated relative cover across the range from 0 to 800 passes. Classes are as follows: VS (0 to 15 percent); SS (16 to 25 percent); N (26 to 35 percent); SR (36 to 50 percent); VR (more than 50 percent).

response, depending upon many of the factors listed above. Bryophytes have generally been found to be quite resistant to damage (Schreiner 1974, 1980; Holmes and Dobson 1976; Studlar 1980), although certain mosses (*Sphagnum* spp., for example) may be sensitive. Lichens are usually sensitive to trampling (Bell and Bliss 1973; Kellomäki and Saastamoinen 1975; Schreiner 1974, 1980).

Effects of Frequency and Timing of Trampling on Vegetation Loss

Clearly, at very high levels of trampling—where all vegetation is destroyed—trampling frequency, whether a given number of passes is spread over a long period of time or concentrated all at once, is irrelevant. Rogova (1976) found that it made no difference if 1,500 passes were applied at a rate of 50 per day every day or 175 per day twice a week.

At lower trampling intensities, however, frequency may make a difference. Hylgaard and Liddle (1981) found that spreading passes over a 4-week period caused more vegetation loss on an *Empetrum nigrum* sand dune heath than concentrating those passes at one time. Singer (1971), Landals and Scotter (1973, 1974), and Nagy and Scotter (1974) also found that in most cases a given number of passes causes less damage at one time than when spread over a long period. In each of these studies, however, confounding factors cloud the picture. In the three latter studies the time between treatment and measurement—a period in which recovery could occur—was longer on the more concentrated treatments;

the phenological stages at which trampling occurred were also different. Hylgaard and Liddle's (1981) one-time treatment occurred at a late date (August 21), when vulnerability may have been low and, as they acknowledge, the time between treatment and measurement was not sufficient to observe the delayed damage that occurs to the dominant plant, *Empetrum nigrum*.

Where recovery of vegetation trampled at different frequencies has been followed for a year or more, making recovery periods approximately equivalent, differences related to frequency of trampling have been minimal (Campbell and Scotter 1975; Douglas and others 1975; Bayfield 1979). Type of vegetation and intensity of trampling had a much greater effect on vegetation cover.

It is difficult, then, to form conclusions about the effect of trampling frequency. Effects are probably different in different vegetation types and they certainly vary with differences in number of passes and the period of time over which use is spread. When the number of passes per period of time is high, the effects of trampling frequency diminish because alteration reaches maximum limits. Common sense suggests that at the other extreme—where a small number of tramples are spread over a very long period of time—concentrated trampling would be more destructive than trampling spread over time. Yet, all studies of trampling frequency have found the opposite. Spreading the trampling out over a growing season causes more damage than concentrating it at one time, even at trampling levels as low as 25 passes per year. Even here, however, the consistent effect of frequency is much less important than other factors.

The effect of seasonality of trampling is also complex and difficult to determine. Again the effect probably varies with such factors as number of passes, morphology and phenology of the constituent plant species, and the seasonality of soil moisture. For example, trampling grasses late in the season, after they have completed their annual growth and reproduction, may have little effect compared to early trampling. Low-growing shrubs, in contrast, are often more susceptible to late-season trampling, because they become increasingly brittle as the season progresses.

Singer (1971) found that vegetation cover was not significantly affected by the time of summer (July 3-August 13) at which trampling occurred. Nagy and Scotter (1974) also found no consistent difference between trampling in early season (early June-early July) and midseason (late July-early August). If pretreatment measurements had been taken and differences in recovery periods had been accounted for, however, it might have been possible to identify meaningful differences for individual species. Holmes and Dobson (1976) found that late season trampling (early September) caused much more cover loss than midseason trampling (early August) for nine of the 14 species that they studied. They attribute this higher vulnerability in late season to reduced plant vigor and drier, more brittle, plant parts. There may, however, be little relationship between cover loss immediately after trampling and cover at some time in the future. Early-season trampling may, for example, have a more profound effect on the stored reserves and reproductive success of the plants, changes that will have a greater effect on future conditions.

WESTERN MONTANA STUDY AREA

The study reported here attempts to extend our knowledge of the relationships discussed in the preceding review. Originally five habitat types were selected for study. The types chosen were those most commonly used for camping at low elevations to midelevations in the Bob Marshall Wilderness. Four of these are forested: *Abies lasiocarpa/Clintonia uniflora* (subalpine fir/queencup beadlily), *Abies lasiocarpa/Vaccinium caespitosum* (subalpine fir/dwarf huckleberry), *Abies lasiocarpa/Xerophyllum tenax* (subalpine fir/beargrass), and *Pseudotsuga menziesii/Symphoricarpos albus* (Douglas-fir/snowberry) (Pfister and others 1977); the other is a grassland: *Festuca scabrella-F. idahoensis* (rough fescue-Idaho fescue) (Mueggler and Stewart 1980). Two replicate experimental plots were established in each type. Following initial sampling, it became clear that the two *Abies lasiocarpa/Clintonia uniflora* plots were different. The ground cover of one was predominantly lush forbs, particularly *Thalictrum occidentale*. This is the *Clintonia uniflora* phase of the type, called ABLA/CLUN hereafter. The other was predominantly low shrubs, such as *Linnaea borealis* and *Arctostaphylos uva-ursi*. This is the *Vaccinium caespitosum* phase of the type, called ABLA/CLUN-VACA hereafter.

All of the experimental plots were located close to roaded access on the fringes of the Bob Marshall Wilderness (fig. 2). The forested plots were all on the Seeley Lake District of the Lolo National Forest; the grassland was on the Montana Department of Fish, Wildlife and Parks' Blackfoot-Clearwater Game Range. All of the plots are located at elevations of 4,200 to 4,400 ft (1 260 to 1 320 m). They are all essentially flat (slopes of 0 to 7 percent), except for the *Pseudotsuga menziesii/Symphoricarpos albus* (PSME/SYAL) plots, which are on a 20 to 25 percent southwest slope.

The ABLA/CLUN plot is located on a stream terrace above Dunham Creek, in a slight concavity at the base of a toe slope. The soil is a Eutric Glossoboralf, with thick organic horizons—4.3 inches (11 cm), a silty loam surface mineral horizon, and an absence of coarse fragments throughout the soil profile. Soil profiles for this and the other habitat types are described in appendix 1.

The overstory on the plot is a dense stand, predominantly of large *Larix occidentalis* and *Picea engelmannii*. *Pinus contorta*, *Abies lasiocarpa*, and *Pseudotsuga menziesii* are also present. Spherical densitometer readings indicate a canopy cover of about 90 percent. The ground cover is dominated by lush forbs, particularly *Thalictrum occidentale*, *Arnica latifolia*, *Smilacina stellata*, and *Clintonia uniflora* (fig. 3). Various shrubs, of which *Berberis repens* is most abundant, are also present. Tables giving cover and frequency for each species on this and other habitat types are in appendix 2.

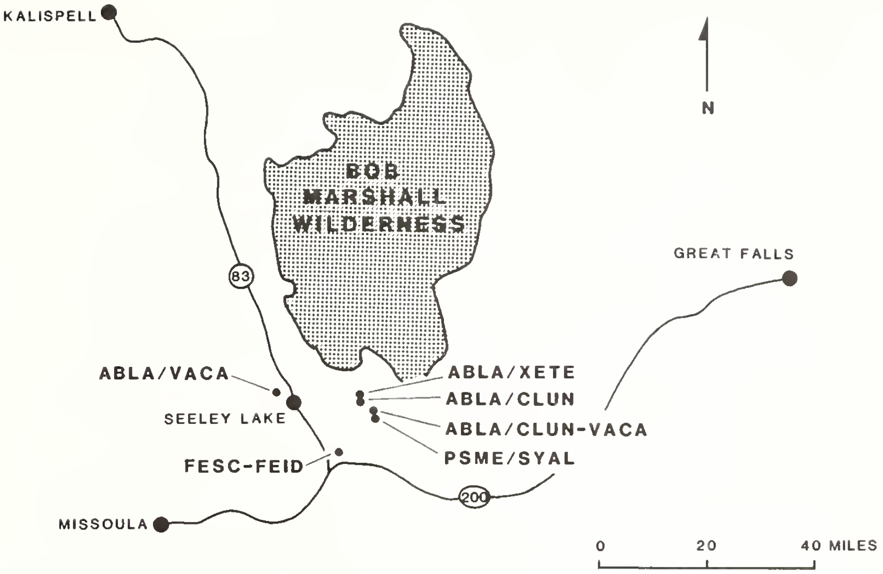


Figure 2.—Location in western Montana of the experimental plots for each of the six habitat types.

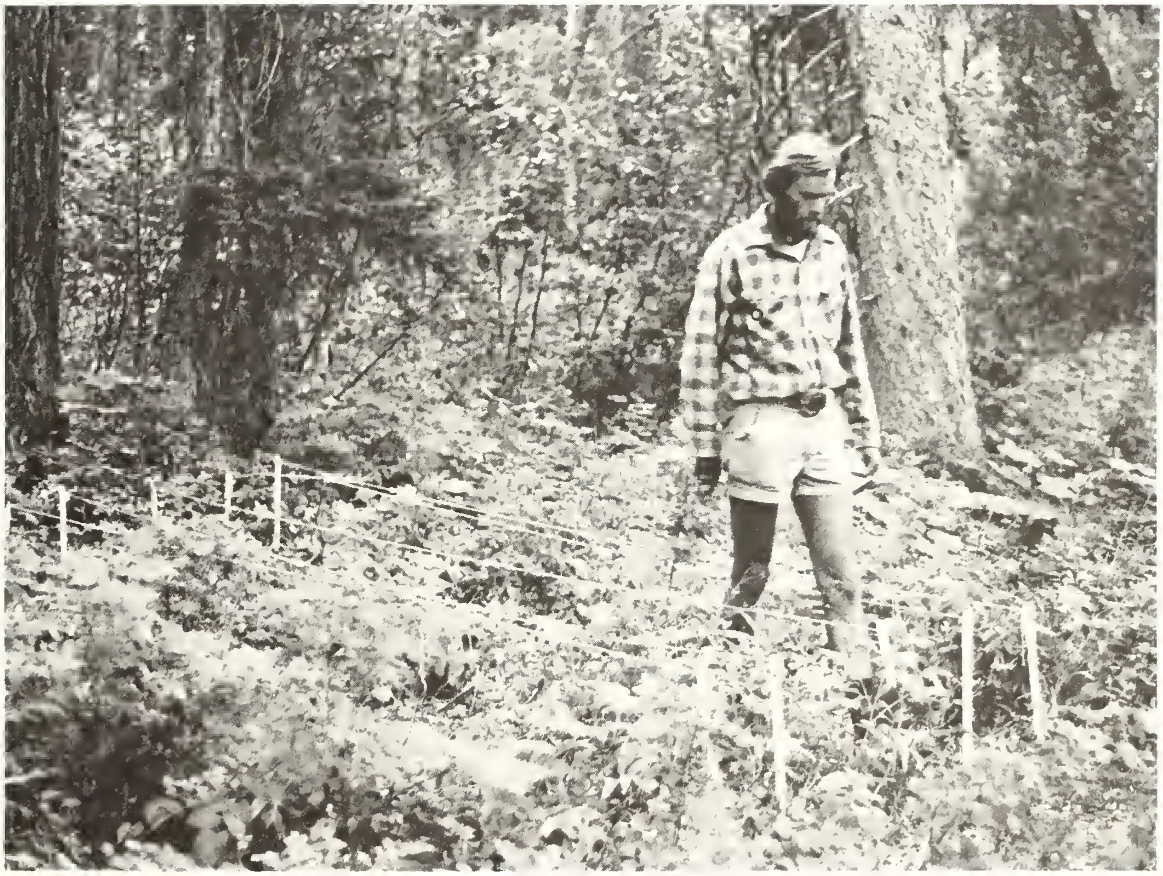


Figure 3.—Closeup of the lush, forb-dominated undergrowth of the Abies lasiocarpa/Clintonia uniflora *plot.*

The ABLA/CLUN-VACA plot is located on a broad flat terrace of glacial outwash near Monture Creek Campground. The soil is a Typic Udorthent, with moderately thick organic horizons—2.4 inches (6 cm), a cobbly sandy loam surface mineral horizon, and 85 percent angular gravel and cobbles throughout the soil profile.

The overstory on the plot is a dense stand, predominantly of moderate-sized *Larix occidentalis*, *Pseudotsuga menziesii*, and *Pinus contorta*. *Pinus ponderosa* and *Picea engelmannii* are also present. Canopy cover is about 90 percent. The ground cover is dominated by low woody species, particularly *Linnaea borealis* (fig. 4). *Berberis repens*, *Spiraea betulifolia*, and *Calamagrostis rubescens* are also abundant.

The *Abies lasiocarpa/Vaccinium caespitosum* (ABLA/VACA) habitat type plots are located on a hummocky bench northwest of Seeley Lake. The soil is an Andic Dystrochrept, with thin organic horizons—1.4 inches (3.5 cm), a cobbly fine sandy loam surface mineral horizon, and gravel and cobbles constituting from 20 percent of the surface horizon to 60 percent of the lower horizons.

On one plot about two-thirds of the mature trees are *Pinus contorta*; the rest are *Larix occidentalis*. Canopy cover is about 65 percent. The other plot is entirely pole-sized *Pinus contorta*, with a canopy coverage of 85 percent. *Abies lasiocarpa* is the most abundantly reproducing tree species. The ground cover of the two plots is similar; they have 21 of 26 species in common and a similarity index, based on relative cover (Bray and Curtis 1957), of 69 percent. *Vaccinium caespitosum* is dominant on both plots. Other abundant species include *Arctostaphylos uva-ursi*, *Xerophyllum tenax*, *Calamagrostis rubescens*, and *Lupinus argenteus* (fig. 5). Mosses, primarily species of *Brachythecium*, are abundant.

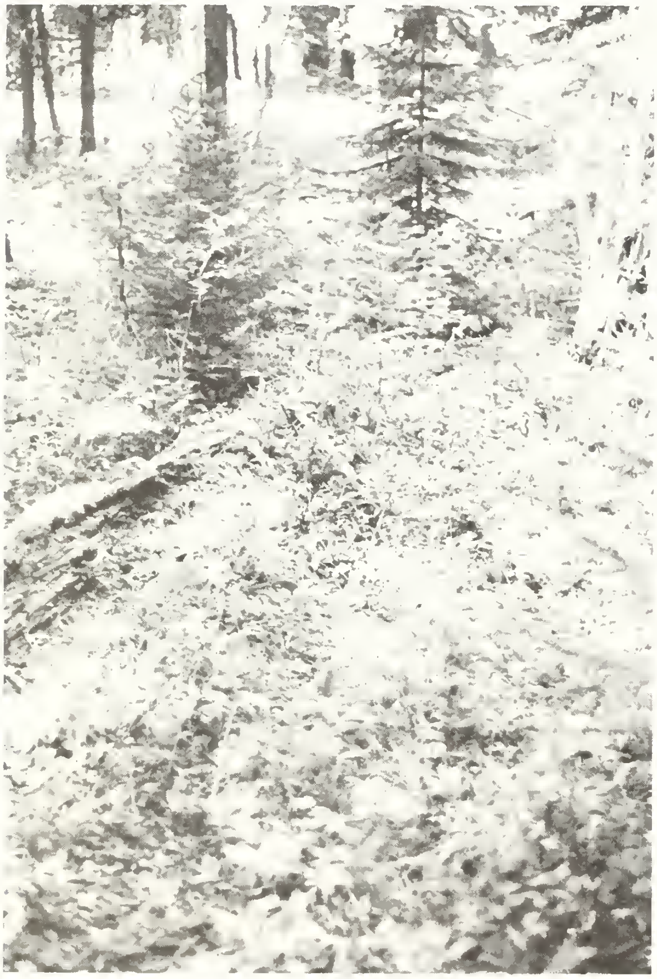


Figure 4.—General view of the vegetation near the Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum *phase plot.*

The *Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare* phase (ABLA/XETE-VAGL) habitat type plots are located on a stream terrace close to the ABLA/CLUN plot above Dunham Creek. The soil is an Andic Dystrochrept, with very thin organic horizons—0.3 inch (0.7 cm), a silt loam surface mineral horizon, and coarse fragment content that increases from 5 percent gravel close to the surface, to 85 percent gravel and cobbles below 11 inches (28 cm).

The overstory on both plots is predominantly pole-sized *Pinus contorta*, with lesser amounts of *Pseudotsuga menziesii*, *Abies lasiocarpa*, and *Larix occidentalis*. Canopy coverage is about 70 percent. The ground cover of the two plots is very similar; 14 of 19 species are shared and the similarity index is 81 percent. *Vaccinium scoparium*, *Xerophyllum tenax*, and *Vaccinium globulare* are the most abundant vascular plants and together comprise about 90 percent of the total vascular plant cover (fig. 6). Mosses, particularly species of *Brachythecium* and *Dicranum*, and lichens, mostly *Cladonia* spp., are especially abundant on these plots.

The *Pseudotsuga menziesii/Symphoricarpos albus-Calamagrostis rubescens* phase (PSME/SYAL-CARU) habitat type plots are located on a side slope about 100 yards (100 m) above Monture Creek. The soil is a Eutric Glossoboralf, with moderately thick organic horizons—2.4 inches (6 cm), a fine gravelly silty loam surface horizon, and coarse fragment content that increases from 30 percent gravel in the surface horizon to 80 percent gravel and cobbles in the lower horizons.

The overstory on both plots is predominantly moderate-sized *Pseudotsuga menziesii* and *Pinus contorta*, with some *Larix occidentalis*. Canopy cover is about 80 percent. The ground cover of the two plots is quite similar (similarity index = 76 percent), although the plots have only 21 of 33 species in common. *Calamagrostis rubescens* is the most abundant plant on both plots. Medium-sized shrubs (<3 ft [1 m] tall) characterize this habitat type (fig. 7). *Spiraea betulifolia*, *Berberis repens*, and *Symphoricarpos albus* are particularly abundant.

The *Festuca scabrella-F. idahoensis* (FESC-FEID) habitat type plots are located on a hilltop and a flat bench 100 ft (30 cm) below the hilltop. The soil is a Typic Haploboroll, with thin organic horizons—1.2 inches (3 cm), a gravelly silty loam surface horizon, and a gravel content of about 45 percent.

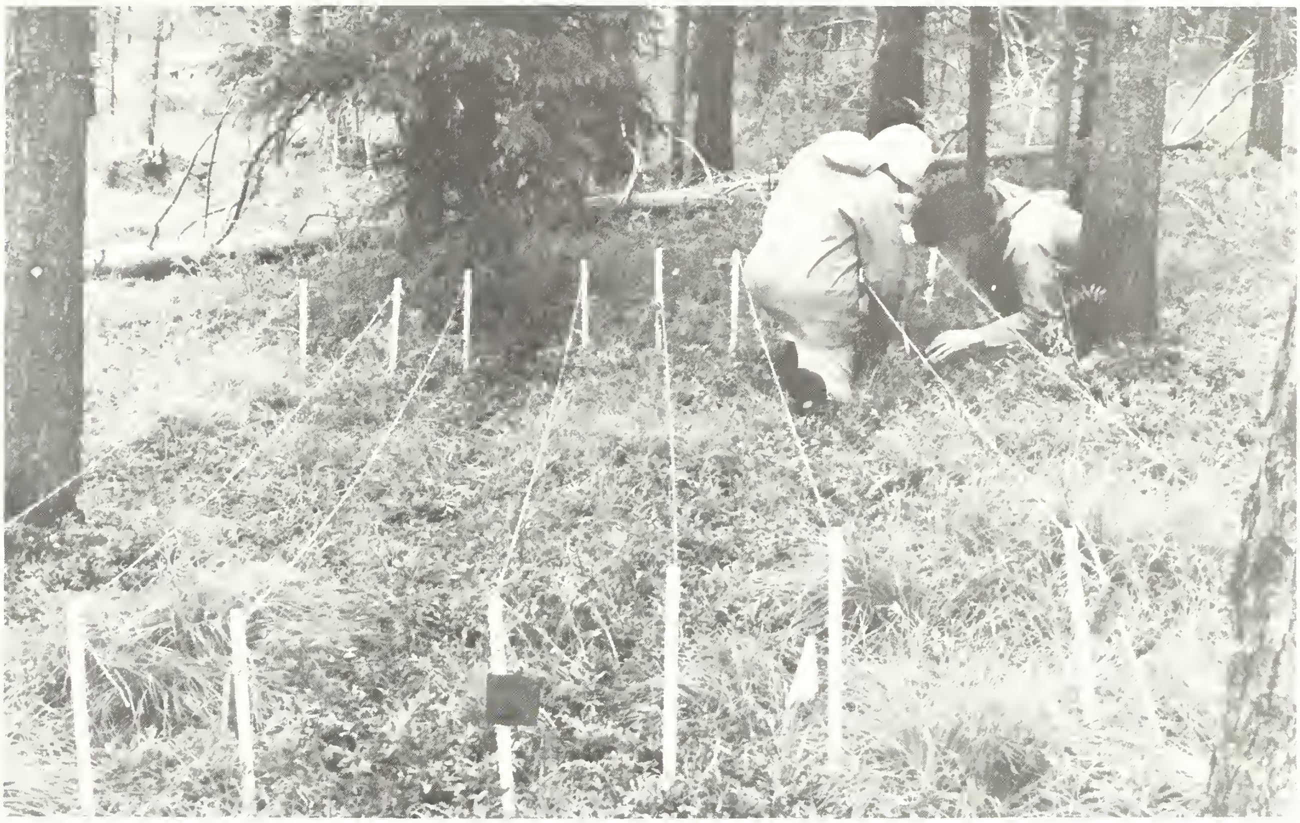


Figure 5.—Treatment lanes in the Abies lasiocarpa/Vaccinium caespitosum *type.*

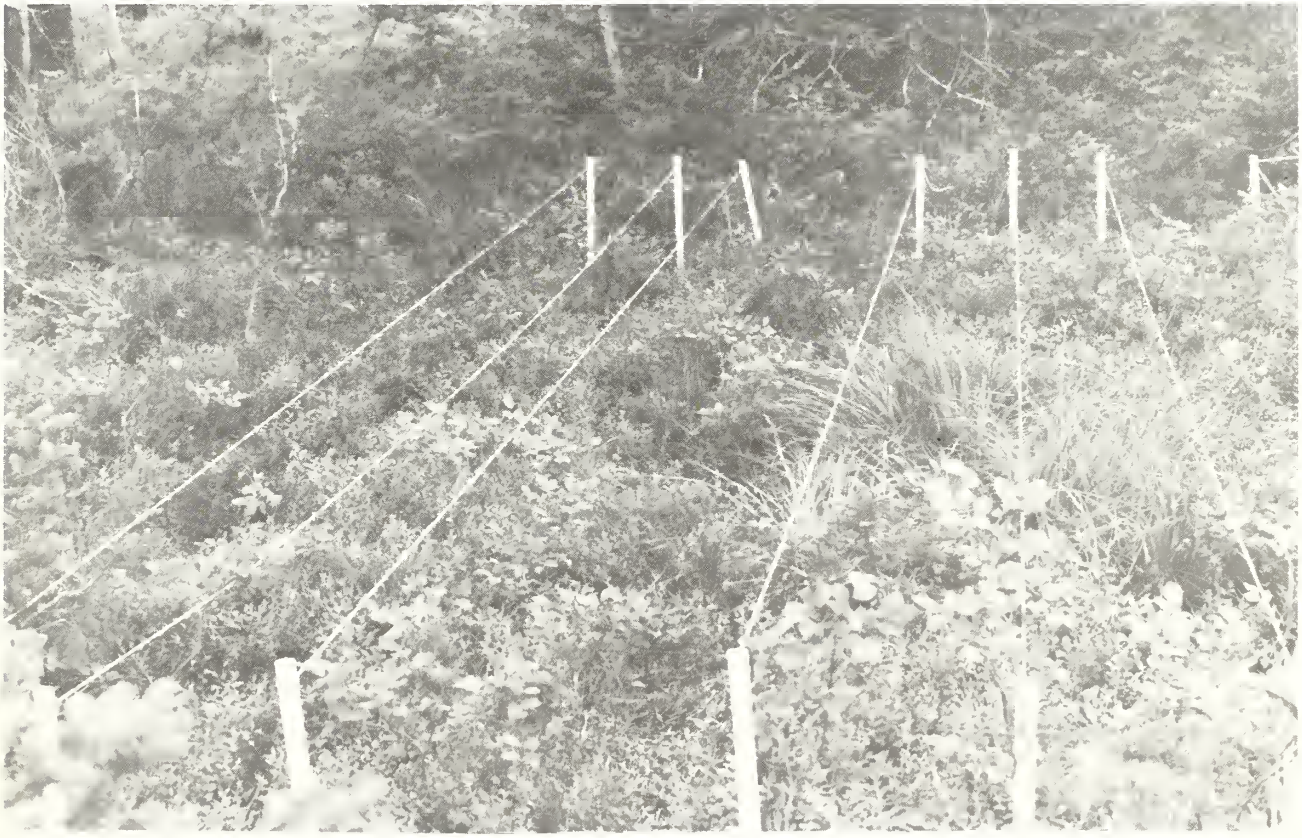


Figure 6.—Treatment lanes in the Abies lasiocarpa/Xerophyllum tenax *type.*

Grasses dominate the vegetation of both plots (fig. 8). In addition to the two dominants, *Festuca scabrella* and *F. idahoensis*, *Koeleria cristata* and *Agropyron spicatum* are the most abundant grasses. *Lupinus sericeus*, *Achillea millefolium*, and *Solidago missouriensis* are common on both plots, but many of the less common species were only found on one or the other of the plots. Despite a similarity index of 65 percent, the two plots have only 15 of 35 species in common.

Figure 7.—General view of the vegetation near the Pseudotsuga menziesii/Symphoricarpos albus *plots.*

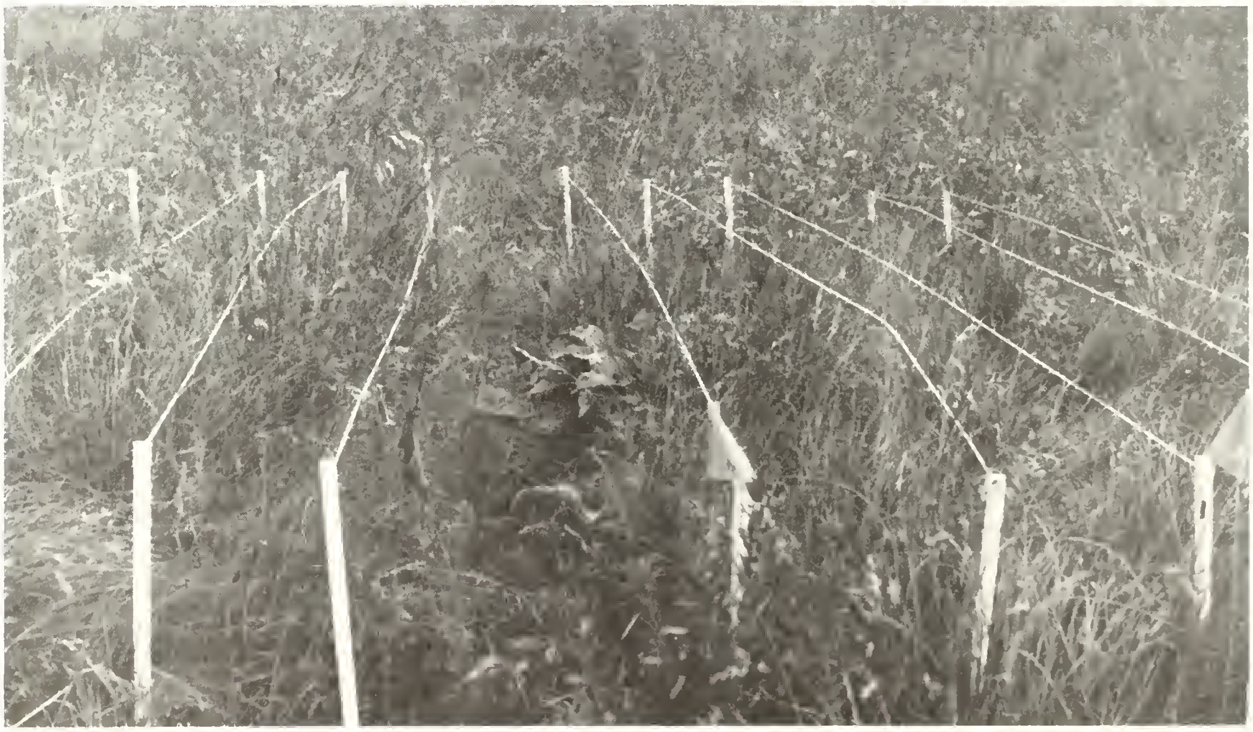


Figure 8.—Treatment lanes in the Festuca scabrella-F. idahoensis *type.*

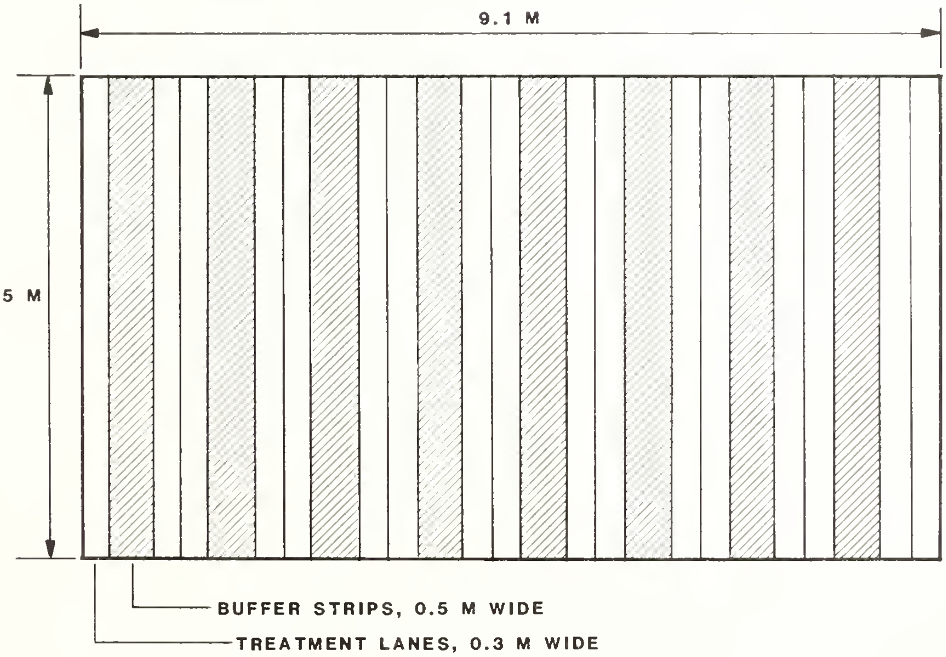
FIELD TECHNIQUES

At each plot, 17 treatment lanes, each 1 ft (0.3 m) wide and about 16 ft (5 m) long, were delineated. Each set of two treatment lanes was separated by a 1.6- by 16-ft (0.5- by 5-m) buffer strip to permit sampling without disturbance of the treatment lanes. Where the land sloped, the lanes were oriented parallel to the contours.

One of the treatment lanes was a control; it was never trampled. The other treatments consisted of four sets of four lanes trampled at the following frequencies throughout the 8-week season: once (1X), three times (3X), eight times (once per week—8X), and 16 times (twice per week—16X). The numbers of passes administered each time to the 1X and 3X lanes were 5, 25, 100, and 300. The 8X and 16X lanes received 5, 25, 75, and 100 passes each time (fig. 9). One pass is a one-way walk along the lane. The total number of passes per season is trampling frequency (1, 3, 8, or 16) times the number of passes. For example, total passes on the four 8X lanes were 40 (8×5), 200 (8×25), 600 (8×75), and 800 (8×100). In each plot, then, one lane received 0, 5, 15, 25, 40, 75, 80, 100, 200, 400, 600, 800, 900, 1,200, and 1,600 total passes per season and two lanes received 300 passes—one in a single treatment and one in three treatments of 100 passes. The treatment assigned to each lane was randomized. All treatments were replicated in a second plot in each habitat type with the exception of the ABLA/CLUN and ABLA/CLUN-VACA types.

Initial measurements were taken on each lane in mid-June 1981. Measurements were taken in four 0.66- by 1.64-ft (2- by 5-dm) subplots, systematically placed—in the center of each lane—3.3, 6.5, 9.8, and 13.1 ft (1, 2, 3, and 4 m) from one end of the lanes. In each subplot the cover of total vegetation, exposed mineral soil, each vascular plant species, and mosses and lichens, each as a group, was estimated to the nearest percent if under 10 percent or in 10-percent coverage classes between 10 and 100 percent.

Trampling commenced the last week of June and continued for 8 weeks until late August. The 1X treatment occurred in late July. The 3X treatments occurred at



16 TREATMENTS, PLUS A CONTROL, WERE RANDOMLY ASSIGNED TO LANES

ONCE/8 WEEKS (1X)

5 PASSES
25 "
100 "
300 "

THREE TIMES/8 WEEKS (3X)

5 PASSES
25 "
100 "
300 "

ONCE/WEEK (8X)

5 PASSES
25 "
75 "
100 "

TWICE/WEEK (16X)

5 PASSES
25 "
75 "
100 "

Figure 9.—Layout of the experimental plot and treatments.

2-week intervals throughout the summer. The twice-per-week (16X) treatments never occurred on consecutive days. Four people, ranging in weight from about 130 lb (60 kg) to 190 lb (85 kg), did the trampling; they all wore lug-soled boots. Followup measurements were taken by the end of August. These were identical to those taken initially. Penetration resistance was measured beneath the unconsolidated surface organic litter layer with a pocket soil penetrometer on each subplot. On the FESC-FEID habitat type, it was so difficult to identify individual grass species after trampling that only the cover of all graminoids combined and of *Festuca scabrella* were recorded.

EFFECTS OF TRAMPLING ON VEGETATION COVER

Change in vegetation cover as a result of trampling was expressed as relative cover. This measure, first suggested by Bayfield (1979), utilizes a correction factor to compensate for inherent variability in cover between treatment lanes and account for changes in cover which occur over the trampling period but which are not caused by trampling. Relative cover is the percentage of original cover that survives trampling, adjusted for any changes occurring on control lanes. It is calculated as follows:

$$\text{Relative cover} = \frac{\text{surviving cover on each trampled subplot}}{\text{initial cover on each trampled subplot}} \times \text{cf} \times 100\%,$$

where

$$\text{cf} = \frac{\text{mean initial cover on four control subplots}}{\text{mean surviving cover on four control subplots}}.$$

The effects on relative cover of the two major controlled variables—amount of trampling and habitat type—were analyzed in a two-way analysis of variance using a factorial design (Steel and Torrie 1960). It was necessary to utilize an inverse sine transformation of the relative cover data to reduce the heterogeneity of variances. With four subplots in each lane and one replication for most habitat types, there were usually eight observations for each treatment in each habitat type. Both of these main effects were significant ($p < 0.001$), as was the interaction between these two variables.

Effect of Trampling Frequency

As reviewed at the beginning of this report, some previous studies have suggested that the effect of a given number of passes varies with trampling frequency. This possibility was examined with an analysis of covariance that tested whether or not relative cover differed significantly with trampling frequency, after statistically controlling differences in the total number of passes. Only in the ABLA/VACA type did frequency of trampling make a significant difference at the 0.05 level (table 2). Here the most concentrated trampling did the least amount of damage. This would corroborate the conclusions of Singer (1971) and Hylgaard and Liddle (1981). Nevertheless, the effects are not pronounced. Even for the ABLA/VACA type, the percentage of variation in relative cover (r^2) explained by both frequency and total number of passes (41 percent) is only 4 percent greater than the r^2 value for just total number of passes.

Another line of evidence supports the conclusion that the effect of trampling frequency is both inconsistent and not a profound factor. Lanes trampled 300 times, once per season (abbreviated 1—300) had the same total number of passes—300—as lanes trampled 100 times, three times per season (3—100). Table 3 presents relative cover after each of these treatments and two other comparisons.

For all habitat types combined, there is a slight, but insignificant (t-test, $\alpha = 0.05$), tendency for concentrated trampling to be more damaging. This tendency, the opposite of what the literature reports, is significant, in all three comparisons, only on the PSME/SYAL type. Most of this difference, however, appears to result from a coincidental greater abundance of resistant species on the lanes that received more frequent trampling. For example, mean moss cover before trampling was 23 percent on the 3—100 lane and 2 percent on the 1—300 lane. Most of the surviving vegetation on the 3—100 lane was moss. Similar differences in species composition

Table 2.—Mean relative cover on lanes treated 1, 3, 8, and 16 times during the season. Means were adjusted, through analysis of covariance, to compensate for differences in the total number of passes they received

Habitat type	Trampling frequency 1X	3X	8X	16X	F	Level of significance
	Adjusted mean relative cover (percent)					
Abies lasiocarpa/Clintonia uniflora	43	34	27	28	0.75	0.53
Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum phase	49	46	37	58	1.59	.20
Abies lasiocarpa/Vaccinium caespitosum	73	50	41	50	4.77	.004
Abies lasiocarpa/Xerophyllum tenax	73	81	76	59	2.09	.11
Pseudotsuga menziesii/Symphoricarpos albus	36	47	32	48	2.30	.08
Festuca scabrella-F. idahoensis	99	100	100	100	.08	.97
All habitat types	70	68	60	64	1.41	.24

Table 3.—Comparisons of mean relative cover for three pairs of treatments with different trampling frequencies but approximately the same number of total passes[1]

Habitat type	Compared treatments								
	1 – 100		16 – 5	3 – 25		16 – 5	1 – 300		3 – 100
	Mean relative cover (percent)								
Abies lasiocarpa/ Clintonia uniflora	39		37	35		37	6		10
Abies lasiocarpa/ Clintonia uniflora-Vaccinium caespitosum phase	53	<	82	79		82	23		19
Abies lasiocarpa/ Vaccinium caespitosum	78		63	53		63	59	>	16
Abies lasiocarpa/ Xerophyllum tenax	77	>	60	96	>	60	38	<	71
Pseudotsuga menziesii/ Symphoricarpos albus	38	<	73	50	<	73	10	<	50
Festuca scabrella-F. idahoensis	99		100	100		100	99		99
All habitat types	67		71	71		71	44		49

[1] The 1—100 treatment, for example, indicates that 100 passes were administered once during the season. < and > symbols between pairs indicate that the more concentrated treatment was more or less damaging, respectively; no symbol indicates no significant difference (t-test; $\alpha = 0.05$).

between treatment lanes—differences that existed prior to treatment—proved to be a major source of uncontrollable variation throughout this experiment.

This study could not prove that frequency of trampling had no effect on amount of impact. However, one can conclude that frequency of trampling has no consistent effect and is less important than total number of passes, habitat type, and local differences in species composition.

Effect of Trampling Intensity

A one-way analysis of variance was used to examine the effect of number of passes on relative cover for each vegetation type (fig. 10). Significant differences between treatments were identified using Duncan's multiple range test ($\alpha = 0.05$) (Steel and Torrie 1960). In each habitat type, cover generally decreased as trampling increased. For some habitat types, however, the rate of decrease was much more rapid than for others. In addition, the general decrease was erratic on some types, namely ABLA/VACA (fig. 10c), ABLA/XETE (fig. 10d), and PSME/SYAL (fig. 10e). These types have patchy representation of particularly resistant species. Lanes in which resistant species were particularly abundant frequently lost less cover than other lanes despite receiving higher levels of trampling.

The relationship between trampling intensity and relative cover is distinctly curvilinear for all five forested habitat types; most of the cover loss occurred after a small number of passes. Increases in trampling beyond 200 to 300 passes caused little additional loss of cover. The data for these types fit closely to a regression line with the form

$$Y = a + b \log X,$$

where Y is transformed (inverse sine) relative vegetation cover and X is number of passes. This corroborates the findings, reviewed earlier, of most other studies.

Of the forested types, cover loss was least rapid in the ABLA/XETE type. In this type more than 75 passes were required to cause a statistically significant reduction in cover (fig. 10d). Beyond this level cover loss was rapid; over 50 percent of the original cover was lost after 400 passes. Further losses of cover were minimal; 37 percent cover survived 1,600 passes. In fact, increasing trampling beyond 300 passes caused no statistically significant increases in cover loss.

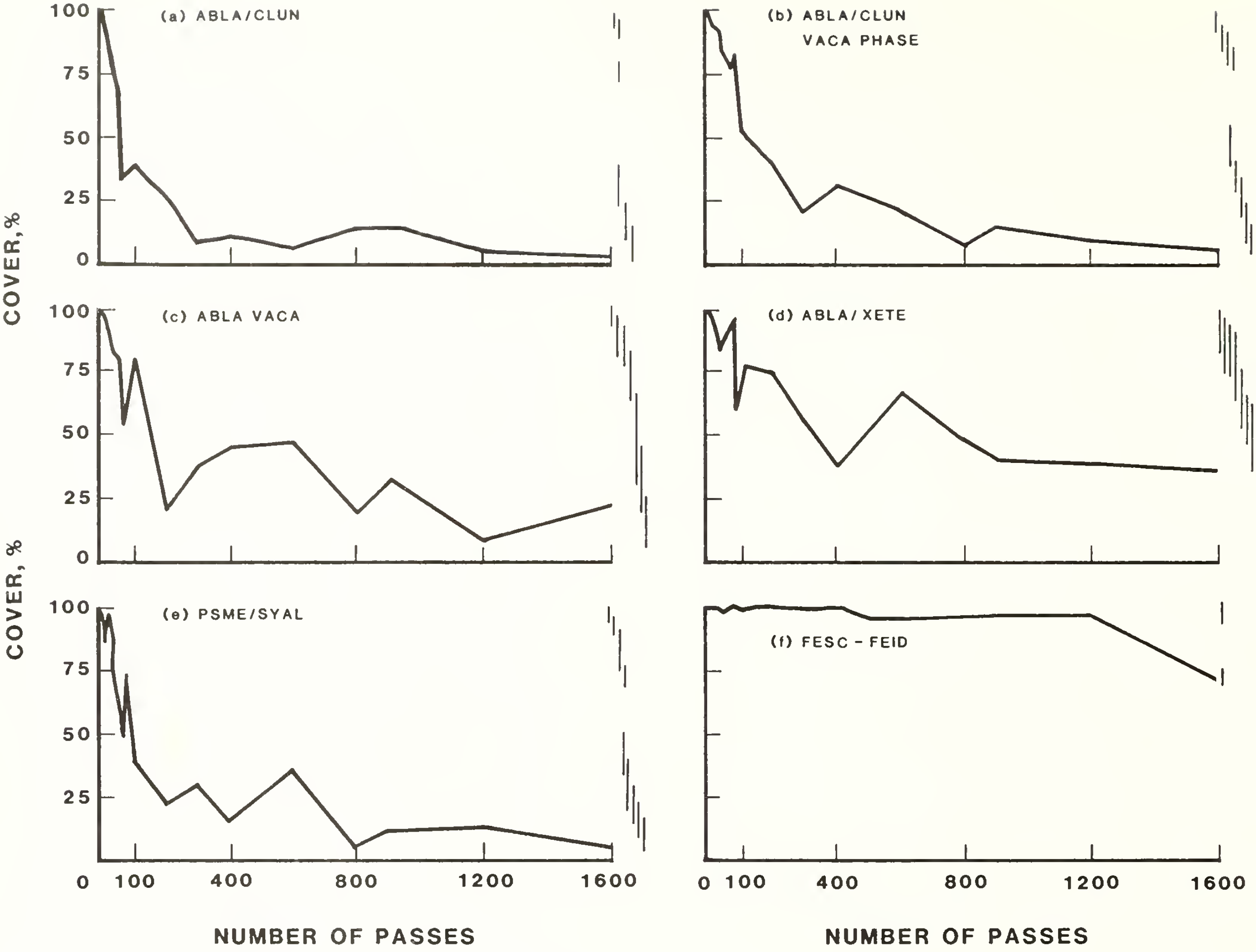


Figure 10.—The relationship between number of passes and relative vegetation cover (percentage of original cover that survives, adjusted for changes on control lanes). Lines at the right of each graph connect values that are not significantly different (Duncan's multiple range test, α = 0.05).

At the other extreme, the most fragile of the forested types was the lush forb-rich ABLA/CLUN type. Here just 15 passes caused a significant loss of cover (fig. 11a, b), and cover loss grew rapidly with increased trampling. Seventy-five passes was sufficient to reduce relative cover to only 35 percent (fig. 11c). Cover was less than 10 percent after 300 passes (fig. 11d), and further increases in trampling caused no significant further reductions in cover (fig. 11e).

In dramatic contrast to the forested types, the FESC-FEID grassland tolerated 1,200 tramples without significant cover loss. Biomass was lost and plants were damaged, but nearly total cover remained. Cover was reduced to 72 percent after 1,600 passes. It is not possible to conclude whether or not the shape of the curve of cover loss beyond the 1,200-pass threshold will also approximate a logarithmic curve as the forested types do.

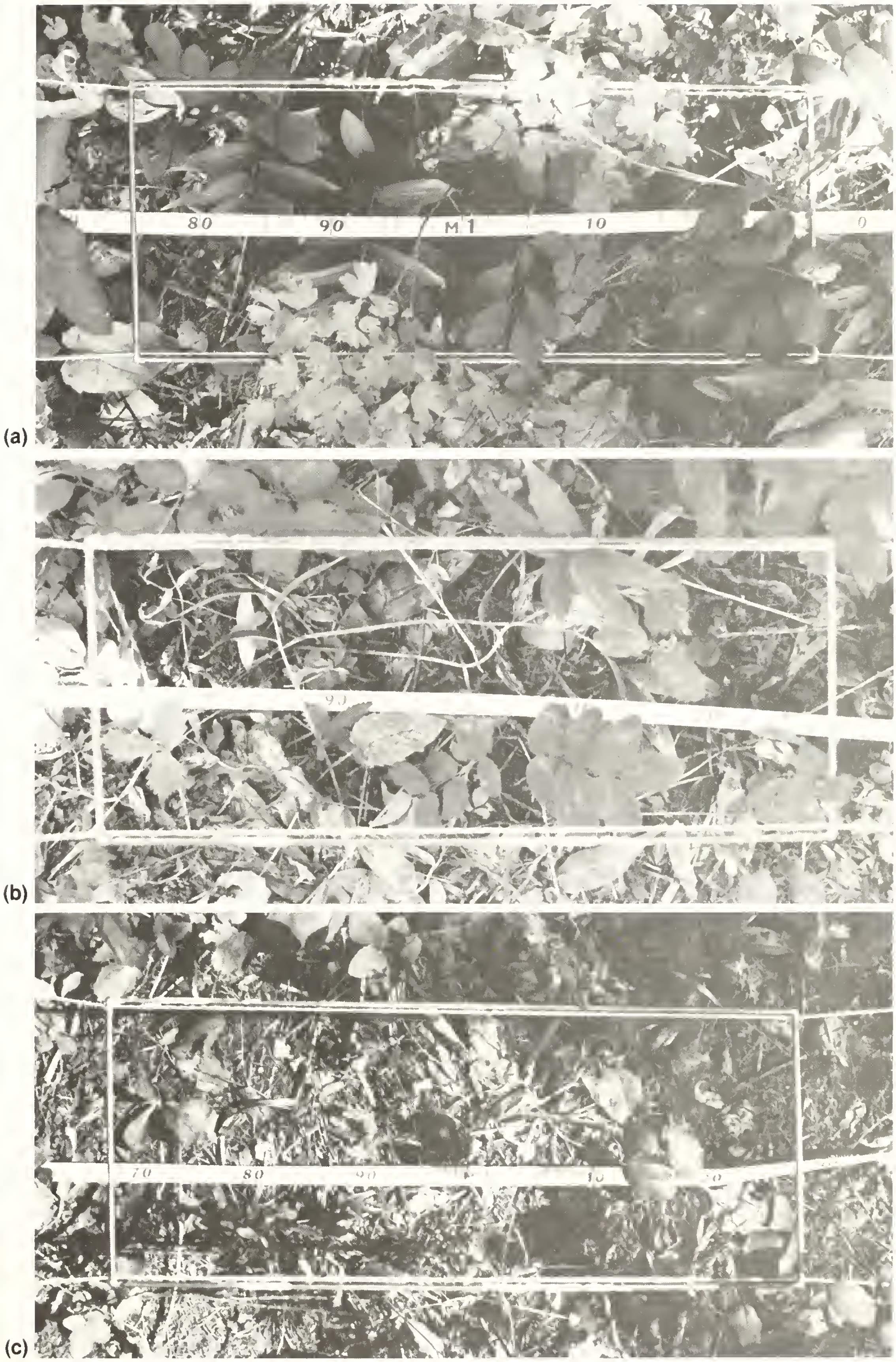


Figure 11.—Vegetation appearance in the Abies lasiocarpa/Clintonia uniflora *habitat type on (a) the control lane and after (b) 15 passes, (c) 75 passes, (d) 300 passes, and (e) 1,200 passes.*

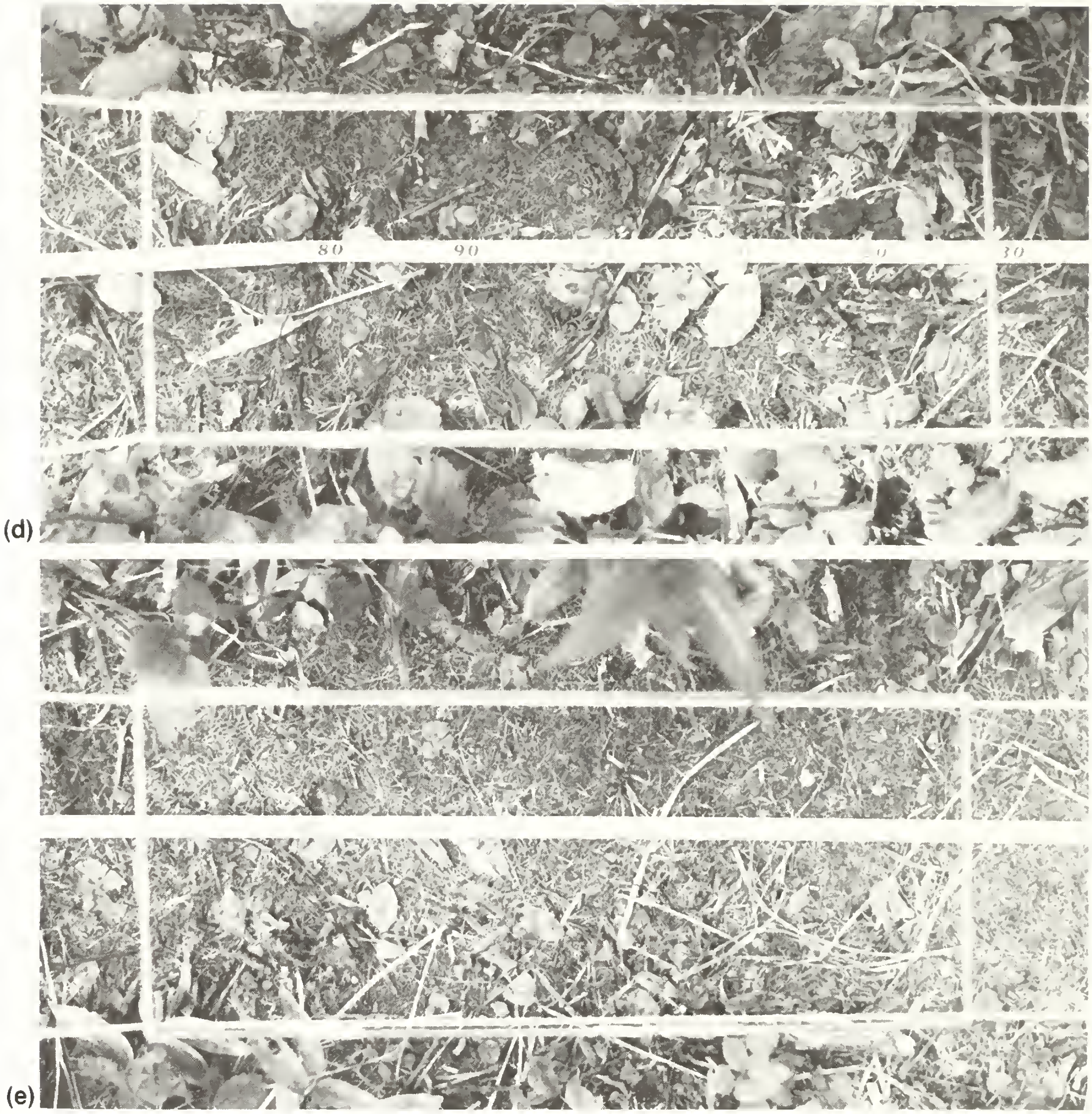


Figure 11. (Con.)

Relative Resistance of Different Habitat Types

A one-way analysis of variance was used to examine the significance of differences in relative cover resulting from differences in the resistance of the six habitat types. Duncan's multiple range test ($\alpha = 0.05$) was used again to identify significant differences between types. Table 4 displays the relative resistance of these types after different numbers of passes.

After as few as 25 passes, some of the more fragile forested types had lost significantly more cover than the FESC-FEID grassland had. Above 75 passes, FESC-FEID was significantly more resistant than all of the forested types, and the most resistant of the forested types, ABLA/XETE, had significantly more cover than ABLA/CLUN, the least resistant habitat type. After 200 passes, ABLA/XETE generally retained significantly more cover than all of the other forested types. Differences between the four least resistant habitat types were most pronounced between 300 and 900 passes. Above 900 passes, cover loss was so great on these four latter types that differentiation diminished.

As indicated in the discussion of previous studies, there are many possible ways of ranking habitat types according to their relative resistance. The number of passes it takes to eliminate more than 50 percent cover was more than 1,600 for FESC-FEID; 400 to 800, depending upon local differences in species composition, for ABLA/XETE; 200 for ABLA/VACA and ABLA/CLUN-VACA; 100 for PSME/SYAL; and 75 for ABLA/CLUN.

Table 4.—Mean percentage relative vegetation cover after various amounts of trampling for each habitat type and for all habitat types combined[1]

Number of passes	Habitat type[2]						All habitat types
	FESC-FEID	ABLA/XETE	ABLA/VACA	ABLA/CLUN-VACA phase	PSME/SYAL	ABLA/CLUN	
5	102a	99a	99a	98a	90b	97a	97
15	100a	93a	95a	95a	96a	92a	95
25	102a	83b	83b	93ab	76b	79b	86
40	99a	89ab	81b	85b	75b	71b	84
75	100a	96a	53c	79b	50c	35c	71
80	100a	60bc	63b	82b	73b	37c	71
100	99a	77b	78b	53c	38c	39c	67
200	100a	74b	20c	41c	22c	26c	50
300	99a	54b	37c	21cd	30c	8d	47
400	100a	39bc	44b	31bc	16c	12c	44
600	95a	67b	46c	22cd	35cd	7d	51
800	96a	48b	19c	8c	6c	15c	36
900	97a	41b	37bc	15cd	12d	15cd	40
1,200	96a	38b	8c	10c	14c	5c	32
1,600	72a	37b	22bc	6c	7c	4c	29
Mean of all amounts	97a	68b	54c	51cd	45d	38d	62

[1] Any two relative vegetation cover values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $\alpha = 0.05$).

[2] Habitat types are:
FESC-FEID = *Festuca scabrella-F. idahoensis*
ABLA/XETE = *Abies lasiocarpa/Xerophyllum tenax*
ABLA/VACA = *Abies lasiocarpa/Vaccinium caespitosum*
ABLA/CLUN-VACA = *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* phase
PSME/SYAL = *Pseudotsuga menziesii/Symphoricarpos albus*
ABLA/CLUN = *Abies lasiocarpa/Clintonia uniflora.*

Table 5.—Relative resistance of the six types[1]

Habitat type	Resistance to: Light trampling	Heavy trampling	Both
Abies lasiocarpa/Clintonia uniflora	SS	N	SS
Pseudotsuga menziesii/Symphoricarpos albus	SS	SS	N
Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum phase	N	N	N
Abies lasiocarpa/Vaccinium caespitosum	N	SR	SR
Abies lasiocarpa/Xerophyllum tenax	VR	VR	VR
Festuca scabrella-F. idahoensis	VR	VR	VR

[1] The indices used here are the same as those in table 1, permitting the resistance of these vegetation types to be compared with types studied previously.

Table 5 summarizes the rankings of the habitat types using the same indices and classes used in table 1 to classify previously studied vegetation types. The FESC-FEID grassland was more resistant than any vegetation type previously studied. The ABLA/XETE type was more resistant than any forested type previously studied. The moderately resistant ABLA/VACA type responded in a manner similar to the *Pinus albicaulis/Vaccinium scoparium* forest (Weaver and Dale 1978), the most resistant forest type studied before this. The three least resistant habitat types, ABLA/CLUN, ABLA/CLUN-VACA, and PSME/SYAL, were about as resistant as the somewhat sensitive *Abies lasiocarpa/Luzula hitchcockii* and *Picea engelmannii/Arnica latifolia* forests of Waterton Lakes National Park (Nagy and Scotter 1974). They were considerably more resistant than some of the most fragile types previously examined.

Two other statistics provide a useful overview of the difference in resistance of these six habitat types. These are the mean relative cover across all of the treatment lanes—the last number in each column in table 4—and the slope of lines regressing transformed relative cover on the logarithm of the number of passes (table 6). Both

Table 6.—Slopes of lines regressing relative vegetation cover on number of passes for each habitat type[1]

Habitat type	Intercept (a)	Slope (b)	r^2	SEE	Significance
Festuca scabrella-F. idahoensis	95.2	−4.3a	0.15	8.9	<0.001
Abies lasiocarpa/Xerophyllum tenax	99.3	−18.7b	.40	19.8	< .001
Abies lasiocarpa/Vaccinium caespitosum	98.4	−23.5c	.57	17.7	< .001
Pseudotsuga menziesii/Symphoricarpos albus	93.2	−24.5c	.73	12.8	< .001
Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum phase	102.7	−27.2cd	.83	10.6	< .001
Abies lasiocarpa/Clintonia uniflora	98.2	−28.8d	.86	10.0	< .001

[1] The exact form of the regression equation used was $Y = a + b \log X$, where Y is relative cover (inverse sine transformed) and X is number of passes. The most resistant habitat types have the least negative slope values. Two slope values followed by the same letter are not significantly different ($\alpha = 0.05$). SEE is the standard error of the estimate.

show the high resistance of FESC-FEID (fig. 12a, b) and the relatively high resistance of ABLA/XETE. The other four types are similar enough in response to make differentiation difficult. Of these four, ABLA/VACA seems to be somewhat more resistant than the rest and ABLA/CLUN seems to be more fragile, but the differences are too slight to have any real significance to management.

One question of considerable interest is whether differences in habitat type or differences in amount of trampling are more important determinants of amount of vegetation loss. Clearly the answer would depend upon the habitat types being compared and the range of trampling pressure applied. If similar vegetation types are subjected to a wide range of use, amount of use will be the more important factor. In contrast, if quite different vegetation types are compared across a narrow range of use—such as 100 versus 200 passes—habitat type is likely to make more difference. The importance of amount of trampling is also highly dependent upon the number of passes. For example, in most habitat types differences in amount of trampling would be much more important when comparing the effects of five and 200 passes than when comparing the effects of 600 and 800 passes.

Across the range of trampling from zero to 1,600 passes, the difference between the grassland and any of the forested types explained more of the variation in relative cover than differences in amount of trampling. That is, in a multiple regression with pairs of habitat types and number of passes as independent variables and relative cover as the dependent variable, the r^2 contribution of habitat type was higher (0.31 to 0.63 depending upon which forested type the grassland was compared to) than the r^2 contribution of number of passes (0.14 to 0.19).

Amount of trampling was more important than differences between any of the forested types across this wide range of trampling intensity. If narrower ranges of trampling are compared, however, some forested habitat type differences become more important. From figures 10a and 10d, it can be seen that between 300 and 1,600 passes, the difference in relative cover related to a difference in number of passes is 11 percent in the ABLA/CLUN type and 17 percent in the ABLA/XETE type. The difference in relative cover between these two types varies from 26 to 60 percent, between 300 and 1,600 passes. This suggests that whether use occurs in ABLA/CLUN or ABLA/XETE has a more profound influence on amount of cover loss than whether amount of trampling is 300 or 1,600 passes. Numerous similar interpretations can be made from these data.

Effect of Local Variations in Species Composition

As mentioned previously, local variations in the initial species composition of different treatment lanes on the same plot appear to have a significant effect on cover loss. Unfortunately, this variability could not be controlled and instead appears as "noise," making it more difficult to interpret the effects of the controlled variables. Nevertheless, the nature and magnitude of this variability is of considerable interest itself.

Let us assume that any time relative cover **increases** with an incremental increase in number of passes (refer to fig. 10), this increase—the opposite of the general trend—is primarily a result of proportionally more resistant species on the more heavily trampled lane. This is a reasonable assumption given that the major variables affecting cover loss should be amount of trampling and the resistance of the plants being trampled. Moreover, most of the treatments with unexpectedly high cover values did have large percentages of resistant species. For example, an analysis of covariance for the ABLA/XETE type showed the amount of variation in relative

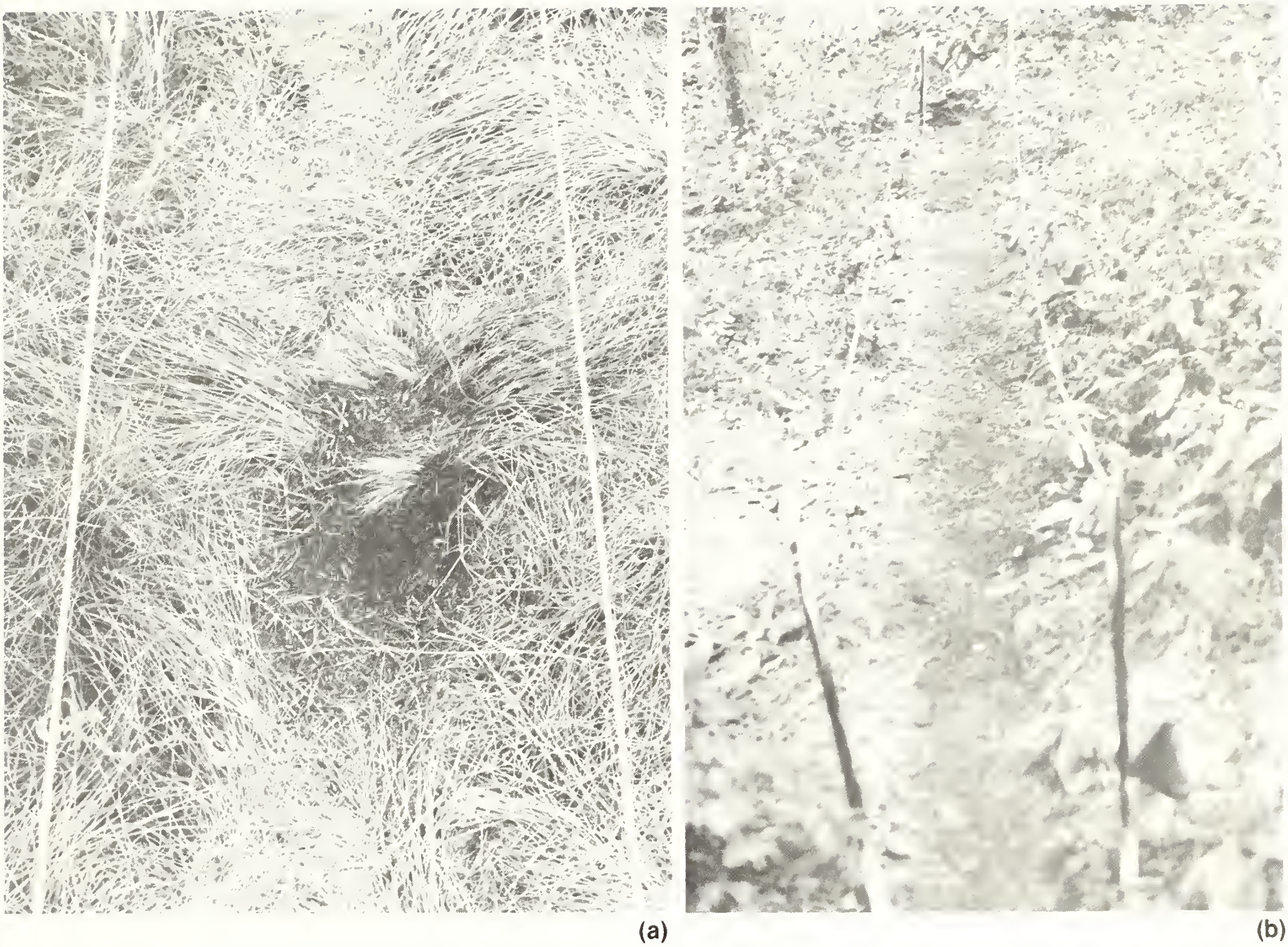


Figure 12.—The effect of 1,600 passes in (a) the resistant Festuca scabrella-F. idahoensis *habitat type and (b) the susceptible* Pseudotsuga menziesii/ Symphoricarpos albus *habitat type.*

cover explained by number of passes increased from 52 percent ($eta^2 = 0.52$) to 72 percent ($r^2 = 0.72$) when pretreatment differences in cover of two resistant plants, *Xerophyllum tenax* and moss, were statistically controlled. In other words, local variation in the distribution of just these two plants accounted for about 40 percent of the variation in cover not explained by trampling intensity. Differences in the distribution of other species probably accounted for much of the rest.

If this assumption about the cause of erratic relative cover values is accepted, then local variations in species distributions—on a scale of a few meters or less—can account for differences in relative cover of as much as 25 percent in the ABLA/VACA, ABLA/XETE, and PSME/SYAL types (fig. 10). *Xerophyllum tenax* and/or mosses are resistant and patchily distributed in these habitat types. The relative importance of these two plants in the treatment lane can often have a greater influence on cover loss than differences in trampling intensity on the order of many hundred passes. For the ABLA/CLUN, ABLA/CLUN-VACA, and FESC-FEID types, local variation in species distribution is not very important. In the first two types, no resistant species are abundant enough to dampen the effect of a given number of passes. In the grassland, resistant species are so abundant and evenly distributed that no lane was inherently more resistant than any other.

EFFECT OF TRAMPLING ON NUMBER OF PLANT SPECIES

Loss of species after trampling was assessed by calculating

$$\text{Species loss} = \frac{\text{number of species before trampling} - \text{number after trampling}}{\text{number of species before trampling}} \times 100\%$$

This loss of species varies significantly both with number of passes and between habitat types; interaction between these two major effects is also significant (two-way analysis of variance; $p < 0.001$).

The graphs in figure 13 show that as number of passes increased from zero to 1,600, loss of species was initially rapid and then leveled off. Most habitat types lost the first quarter of their species by 75 to 100 passes and the second quarter by 400 passes; a further increase in trampling to 1,600 passes caused an additional loss of only 10 to 15 percent.

Initial loss of species was most rapid in the ABLA/VACA (fig. 13c) and PSME/SYAL (fig. 13e) types; it was least rapid in the FESC-FEID (fig. 13f) and ABLA/XETE (fig. 13d) types. Generally, the initial rapid loss of species began to abate after 25 passes, increasing more slowly to 400 passes. In the ABLA/CLUN type (fig. 13a), the initial rapid loss continued unabated to 300 passes,

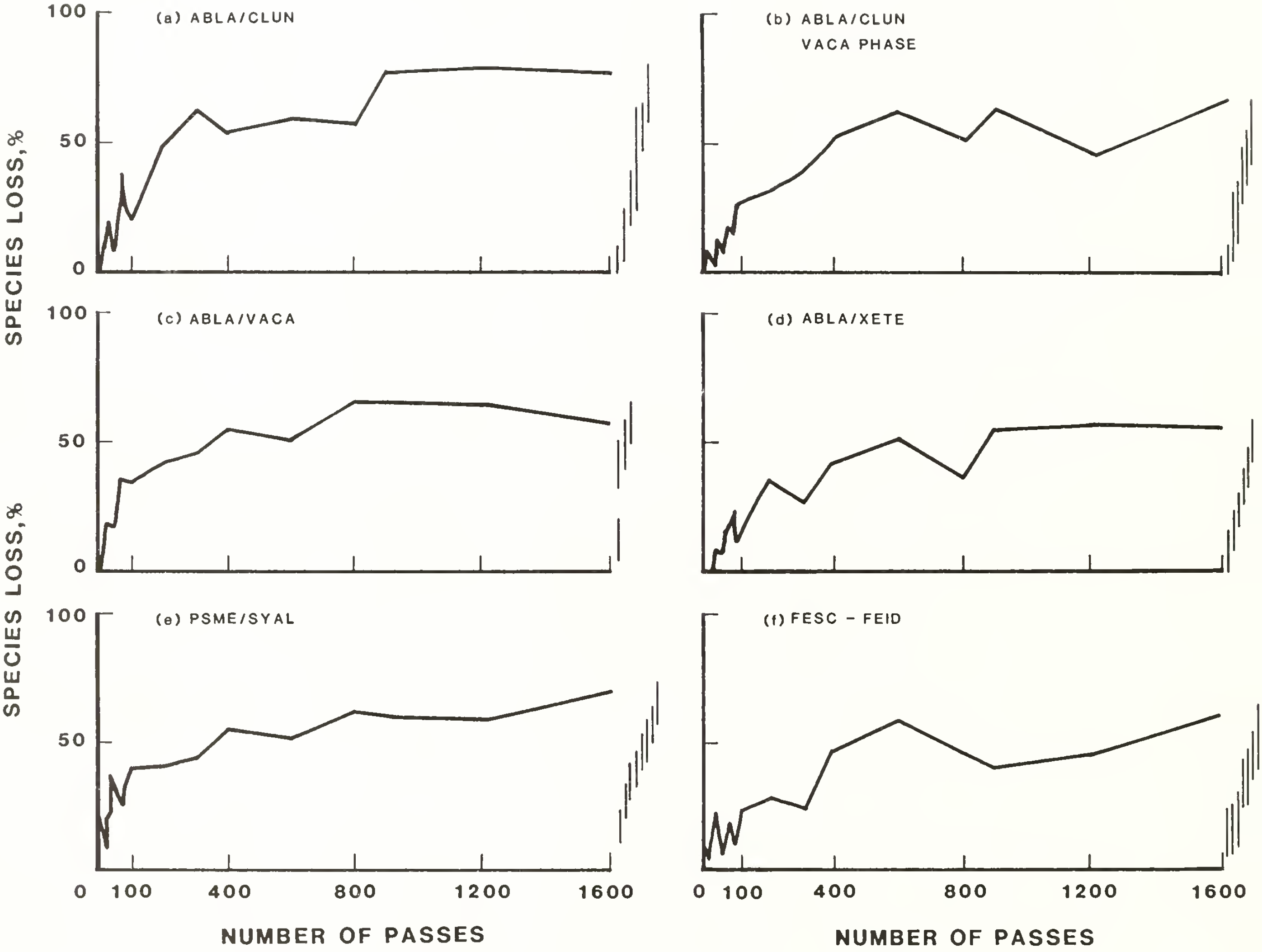


Figure 13.—The relationship between number of passes and species loss (percentage of species originally present that were absent after trampling). Lines at the right of each graph connect values that are not significantly different (Duncan's multiple range test, α = 0.05).

Table 7.—Mean percentage species loss after various amounts of trampling for each habitat type and for all habitat types combined[1]

Number of passes	Habitat type[2]						All habitat types
	ABLA/ XETE	FESC-FEID	ABLA/CLUN-VACA phase	ABLA/ VACA	PSME/ SYAL	ABLA/ CLUN	
5	0a	5a	7a	9a	10a	7a	6
15	8a	23a	2a	17a	20a	8a	15
25	8a	20a	8a	18a	22a	20a	16
40	10a	11a	7a	17a	33b	10a	16
75	19a	17a	16a	35a	26a	38a	25
80	23abc	14a	16ab	35c	33bc	24abc	25
100	14a	24ab	27ab	35b	38b	21ab	27
200	37a	28a	32a	42a	39a	50a	37
300	29ab	24a	40abc	46c	42bc	64d	39
400	44a	47a	53a	55a	54a	56a	51
600	53a	58a	63a	51a	51a	61a	55
800	38a	45ab	51abc	66c	61c	59bc	53
900	56b	40a	64bc	65bc	59b	79c	58
1,200	58ab	43a	46ab	66bc	58ab	81c	58
1,600	57a	58a	65a	58a	69a	79a	63
All amounts	28a	29a	31a	39b	40b	42b	35

[1] Any two mean percentage species loss values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, $\alpha = 0.05$).

[2] Habitat types are:
ABLA/XETE = *Abies lasiocarpa/Xerophyllum tenax*
FESC-FEID = *Festuca scabrella-F. idahoensis*
ABLA/CLUN-VACA = *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* phase
ABLA/VACA = *Abies lasiocarpa/Vaccinium caespitosum*
PSME/SYAL = *Pseudotsuga menziesii/Symphoricarpos albus*
ABLA/CLUN = *Abies lasiocarpa/Clintonia uniflora.*

after which 64 percent of the species were lost. This type eventually lost about 80 percent of its species at trampling levels of 900, 1,200, and 1,600 passes.

The relative resistance of these types is displayed in table 7. Over the entire range of trampling intensity, ABLA/VACA, PSME/SYAL, and ABLA/CLUN were more prone to species loss than ABLA/XETE, FESC-FEID, and ABLA/CLUN-VACA; however, differences were not as pronounced as for resistance to cover loss.

RESPONSE OF INDIVIDUAL SPECIES TO TRAMPLING

We were able to calculate relative cover and to graph response to trampling for species abundant on control lanes and most treated lanes (fig. 14). Cover loss for individual species is generally more rapid than for total cover. The rate for individual species is actually a more accurate reflection of how rapidly vegetation is lost, because pretreatment total cover measures are underestimated on account of multitiered vegetation cover. Median relative cover for the 19 species fell below 50 percent after 40 to 75 passes and below 30 percent after 100 passes. It declined more slowly to 6 to 7 percent after 400 passes and then even more slowly to 1 to 2 percent after 1,600 passes.

The most sensitive species, *Thalictrum occidentale*, *Osmorhiza chilensis*, and *Melampyrum lineare*, all lost most of their cover after 15 passes and were all but eliminated—at least for the season—after 40 passes. They are all forbs adapted to tolerate low sunlight conditions. Such adaptations—thin cuticles, cell walls, and stems, and a large amount of supportive and conductive tissue—make them susceptible to breakage (Cole 1979).

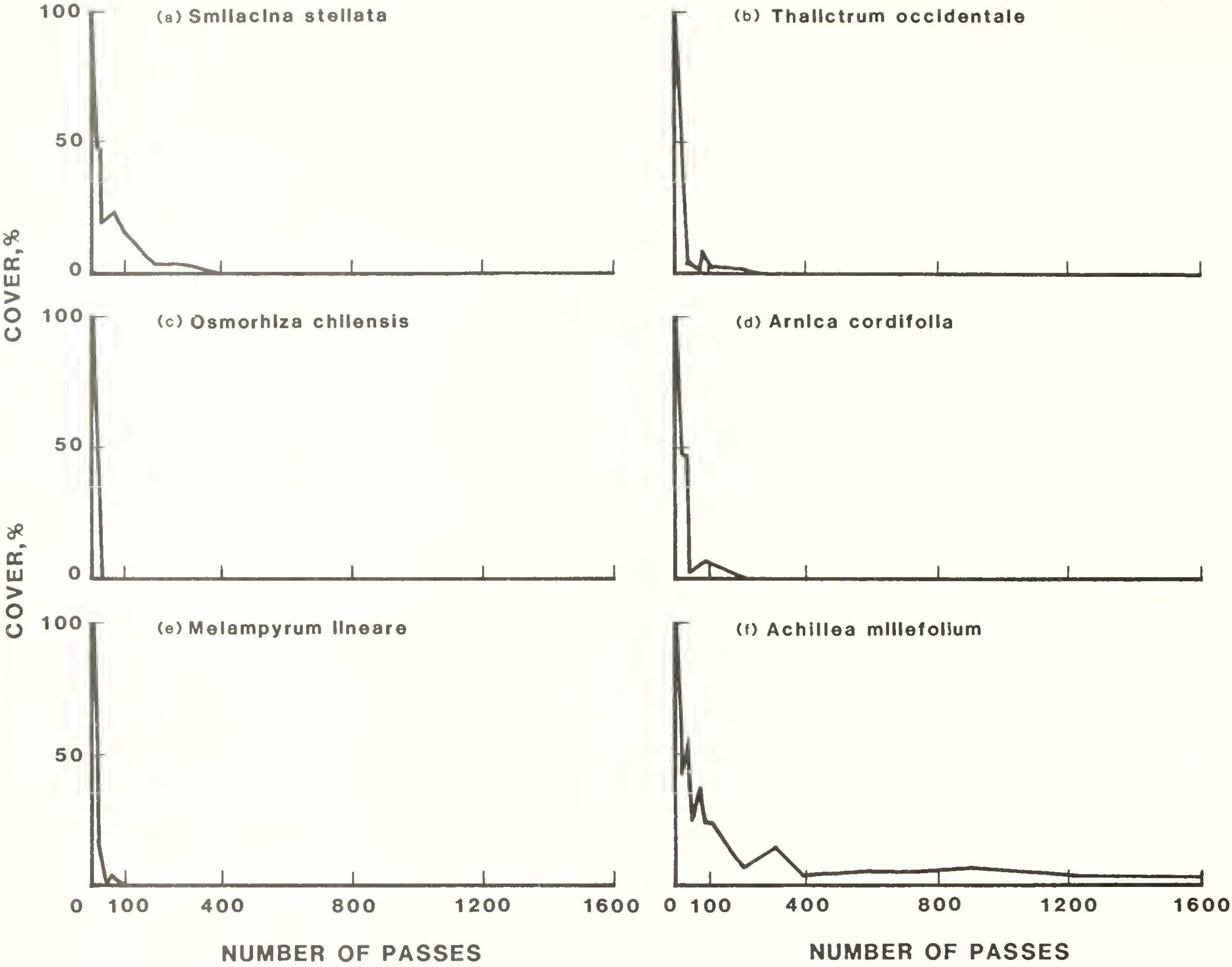


*Figure 14.—The relationship between number of passes and relative cover (percentage of original cover that survives, adjusted for changes on control lanes) for the most common vascular species and for mosses and lichens as a group. The * denotes species for which data from more than one habitat type have been averaged.*

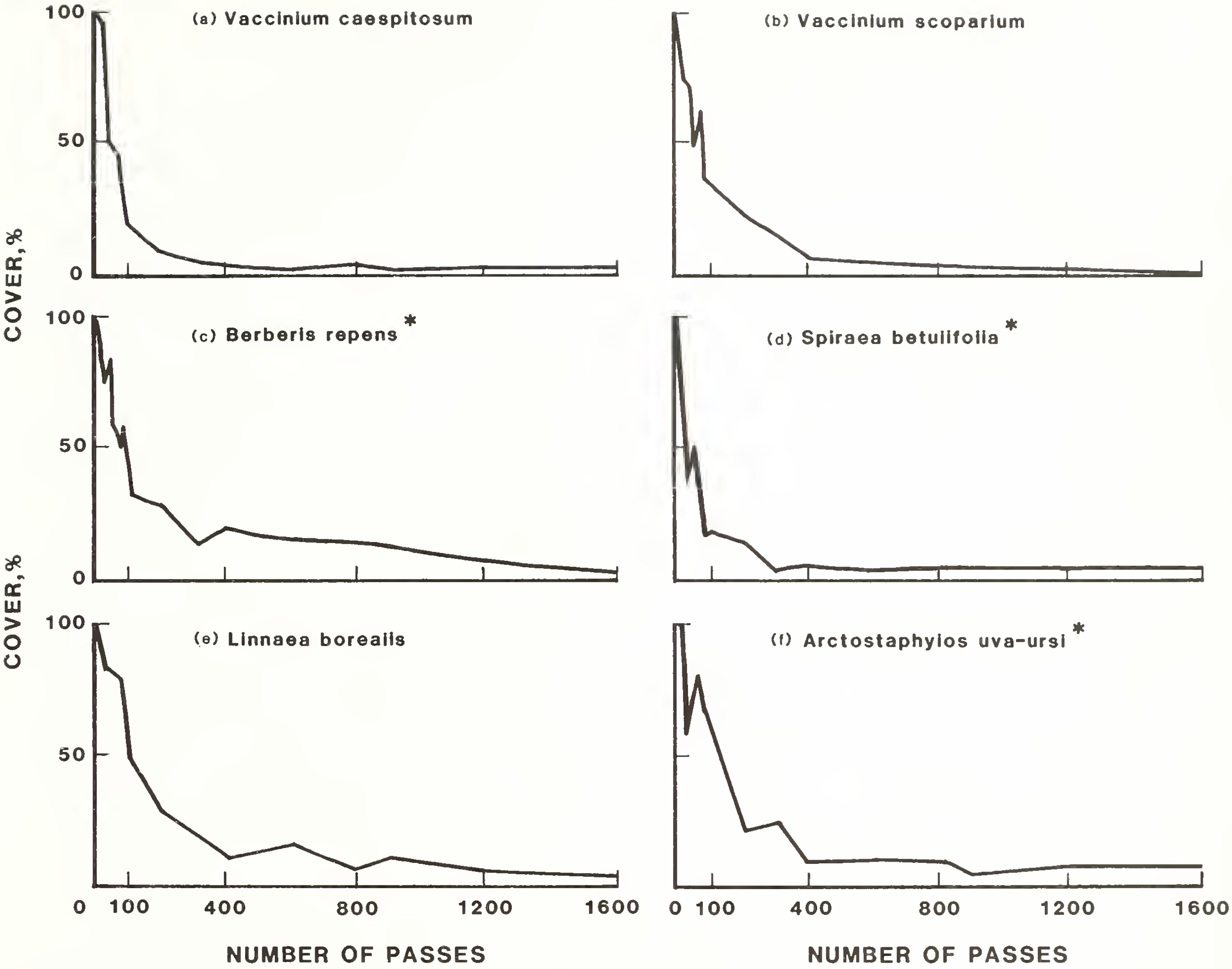


Figure 14. (Con.)

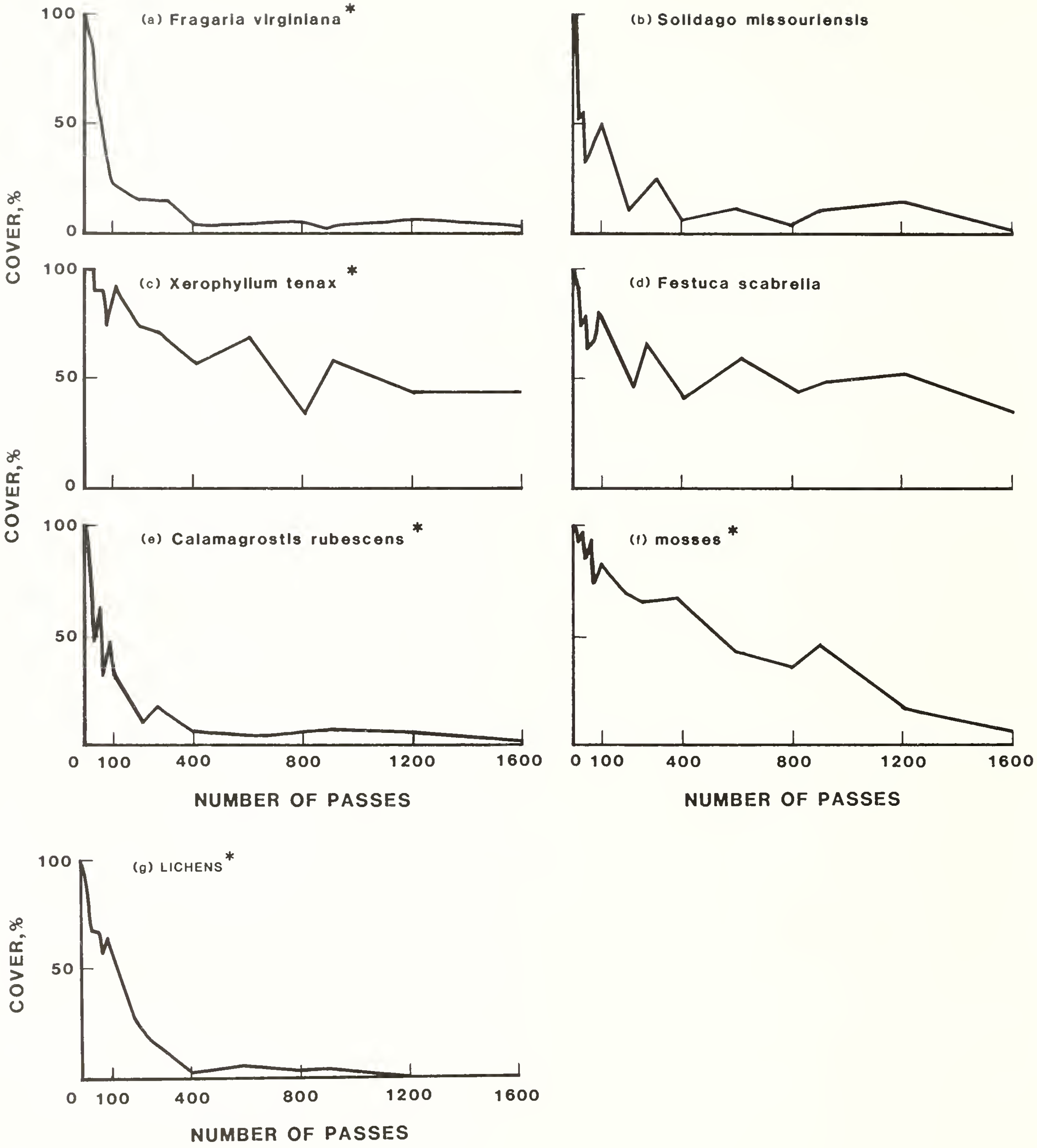


Figure 14. (Con.)

Achillea millefolium and *Fragaria virginiana* were less susceptible but were nearly eliminated after 400 passes. Leaves close to the ground allow these two forbs to survive low levels of trampling. Tough, flexible, straplike leaves and a tufted growth form combine to make *Xerophyllum tenax*, a forb, the most resistant of all plants studied (fig. 15a, b). It is important to note that even this most resistant species exhibited no threshold below which trampling had little effect and above which effects were pronounced. Instead, cover loss was immediate, the rate of loss declining as trampling intensity increased.

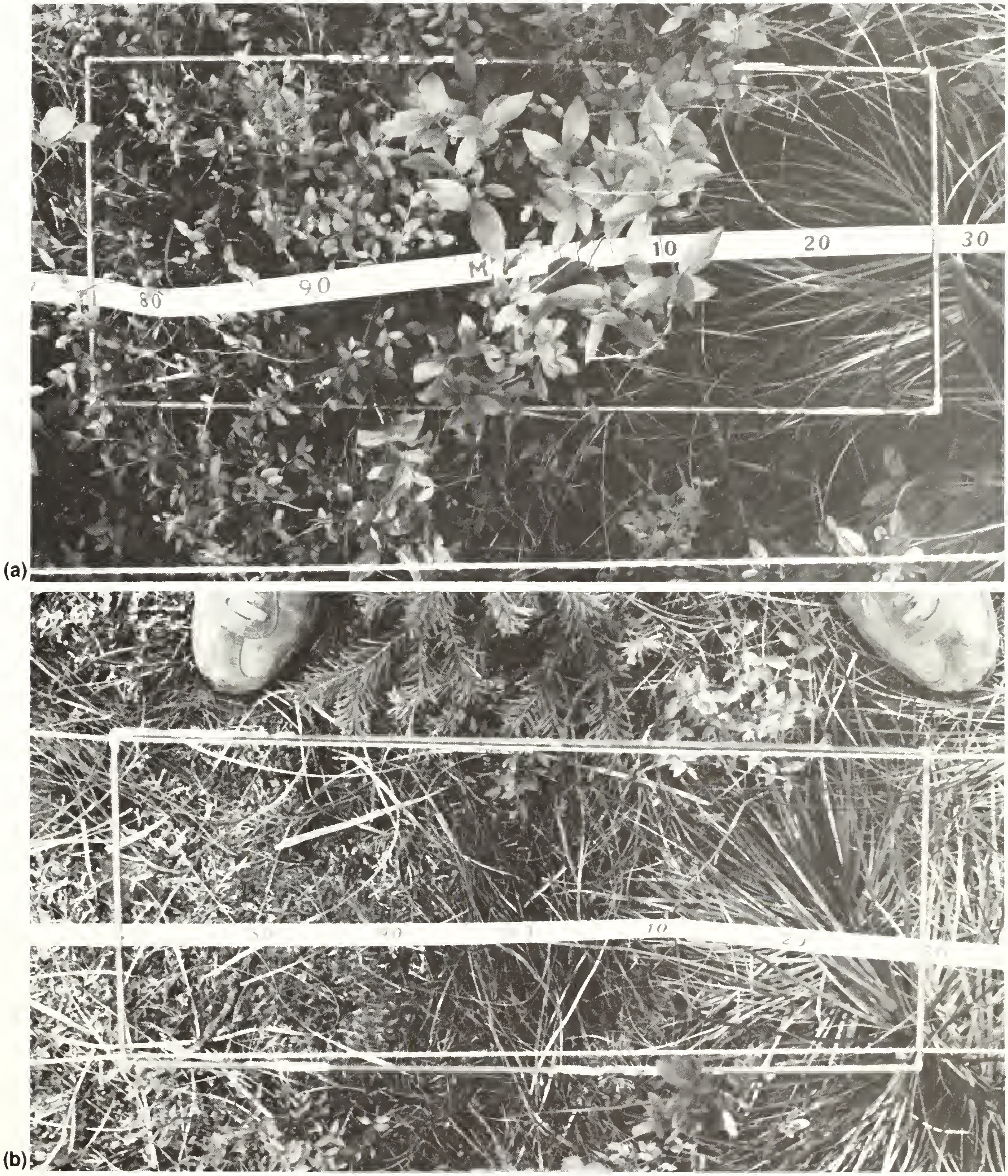


Figure 15.—Vegetation of the 200-pass lane on the Abies lasiocarpa/Xerophyllum tenax *habitat type, (a) before and (b) after treatment.* Xerophyllum tenax *and moss survive, but* Vaccinium scoparium *and* V. globulare *do not.*

Shrubs generally were more resistant than forbs to the immediate effects of trampling. But, none of the shrubs were highly resistant. The most resistant common shrub, *Berberis repens*, lost 80 percent of its cover after 300 passes. The reader should remember that these results do not account for susceptibility to prolonged trampling or ability to recover. Studies of established campsites and trails suggest that most shrubs are relatively susceptible to prolonged trampling (Dale and Weaver 1974; Cole 1982a, 1983).

The two graminoids responded quite differently. The bunchgrass, *Festuca scabrella*, was very resistant. Even after 1,600 tramples, about 35 percent of the plant's cover survived. This was usually the tough core of the tuft (fig. 16). *Calamagrostis rubescens*, a rhizomatous grass, was not particularly resistant and lost over 90 percent of its cover after 400 passes.

Mosses were very resistant, particularly to low and moderate levels of trampling (fig. 15a, b). This is the one type of plant that did not exhibit a curvilinear relationship between cover loss and amount of trampling. Two-thirds of the moss cover survived 400 passes. Beyond this level of trampling, cover loss was rapid and continued unabated; only about 5 percent survived 1,600 passes. Lichens were considerably more sensitive, but, like mosses, consistently survived low levels of trampling. Over 60 percent of the cover survived 100 passes. Beyond this level, cover dropped rapidly to less than 5 percent after 400 passes.

All of these species and 34 less widely distributed species are classified according to their susceptibility in table 8. This ranking can be used to predict the resistance of vegetation types to the initial effects of trampling. Types dominated by resistant species will obviously be more resistant than those dominated by susceptible species. For example, the most resistant habitat types, FESC-FEID and ABLA/XETE, have 74 and 73 percent cover of very resistant species, compared with 0 and 1 percent cover of very susceptible species. In the PSME/SYAL, ABLA/VACA, and ABLA/CLUN-VACA types, very susceptible species are slightly more abundant than very resistant species. In the ABLA/ CLUN type, very sensitive species contribute 59 percent cover compared to 5 percent for very resistant species.

From table 8, graminoids have been classified as very resistant, resistant, and neutral. The bunchgrass, *Festuca scabrella*, is most resistant. Previous studies have generally found graminoids to be particularly resistant to trampling (Schreiner 1974, 1980; Nagy and Scotter 1974). These results, along with those of Nagy and Scotter (1974), suggest that graminoids growing under shady forested conditions are generally more sensitive than graminoids growing in the open. Graminoids that evolved under grazing pressure should also be more resistant than those that did not.

Shrubs range from sensitive to resistant; none are exceptionally sensitive or exceptionally resistant. The more resistant shrubs are over 2 ft (0.6 m) tall (*Amelanchier alnifolia*), very low-growing (*Arctostaphylos uva-ursi, Linnaea borealis*), and/or have tough, flexible branches and leaves (*Berberis repens*). The most susceptible shrubs (*Vaccinium caespitosum, V. globulare, Spiraea betulifolia*) are short, erect shrubs with brittle stems. Brittleness increases with the season, making these species particularly susceptible to trampling later in the summer.

These results agree with results of a series of Canadian studies (Landals and Scotter 1973, 1974; Nagy and Scotter 1974) in which *Berberis repens* and *Vaccinium scoparium* were found more resistant than *Symphoricarpos albus, Vaccinium membranaceum*—a morphological analog to *V. globulare*—and *Spiraea betulifolia*. Differences were slight, however, when considering the general susceptibility of these shrubs.

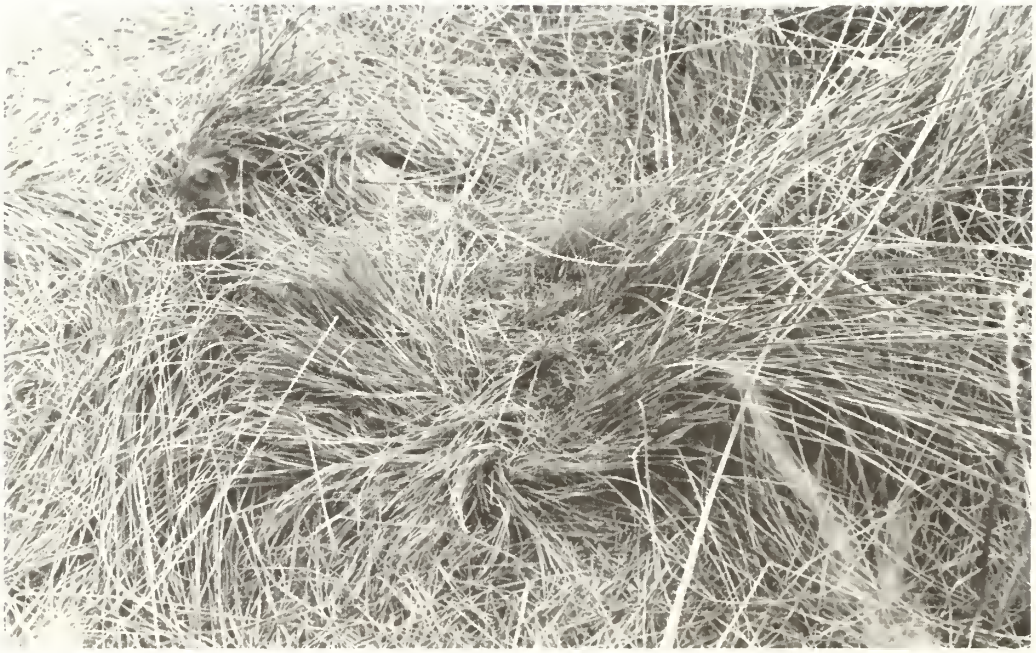


Figure 16.—After 1,200 passes, Festuca scabrella *is severely abraded but the tough core of the tuft survives.*

Table 8.—Classification of the more abundant species according to their sensitivity to trampling[1]

VERY RESISTANT
- *Carex geyeri* (elk sedge)
- *Festuca scabrella* (rough fescue)
- *Arenaria congesta* (capitate sandwort)
- *Penstemon confertus/P. procerus* (yellow/small-flowered beardtongue)
- *Xerophyllum tenax* (beargrass)
- mosses

RESISTANT
- *Amelanchier alnifolia* (western serviceberry)
- *Arctostaphylos uva-ursi* (kinnikinnick)
- *Berberis repens* (creeping Oregongrape)
- *Linnaea borealis* (twinflower)
- *Rosa acicularis* (prickly rose)
- *Rosa gymnocarpa* (baldhip rose)
- *Carex concinnoides* (northwest sedge)
- *Antennaria microphylla/A. umbrinella* (rosy/umber pussy-toes)
- *Antennaria racemosa* (raceme pussy-toes)
- *Chimaphila umbellata* (prince's-pine)
- *Chrysopsis villosa* (hairy golden-aster)
- *Solidago missouriensis* (Missouri goldenrod)
- *Viola orbiculata* (round-leaved violet)

NEITHER RESISTANT NOR SENSITIVE
- *Pachistima myrsinites* (mountain-lover)
- *Rubus parviflorus* (thimbleberry)
- *Symphoricarpos albus* (snowberry)
- *Vaccinium scoparium* (grouse whortleberry)
- *Bromus vulgaris* (Columbia brome)
- *Calamagrostis rubescens* (pine grass)
- *Achillea millefolium* (common yarrow)
- *Aster foliaceus* (leafy aster)
- *Fragaria virginiana* (blueleaf strawberry)
- *Potentilla gracilis* (slender cinquefoil)
- tree seedlings
- lichens

SENSITIVE
- *Spiraea betulifolia* (shiny-leaf spirea)
- *Vaccinium caespitosum* (dwarf huckleberry)
- *Vaccinium globulare* (globe huckleberry)
- *Arnica cordifolia/A. latifolia* (heartleaf/mountain arnica)
- *Aster conspicuus* (showy aster)
- *Fragaria vesca* (woods strawberry)
- *Galium boreale* (northern bedstraw)
- *Geranium viscosissimum* (sticky purple geranium)
- *Hieracium albiflorum* (white-flowered hawkweed)
- *Lupinus sericeus* (silky lupine)
- *Smilacina stellata* (starry false Solomon's seal)

VERY SENSITIVE
- *Adenocaulon bicolor* (pathfinder)
- *Clintonia uniflora* (queencup beadlily)
- *Disporum trachycarpum* (Sierra ferry-bell)
- *Epilobium angustifolium* (fireweed)
- *Galium triflorum* (fragrant bedstraw)
- *Hedysarum occidentale* (western sweetvetch)
- *Lupinus argenteus* (silvery lupine)
- *Melampyrum lineare* (narrow-leaved cow-wheat)
- *Osmorhiza chilensis* (mountain sweet-root)
- *Thalictrum occidentale* (western meadowrue)
- *Viola adunca* (early blue violet)

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[1] Classification guidelines were: very resistant if relative cover was greater than 30 percent after 400 passes; resistant if relative cover was greater than 30 percent after 100 passes and greater than 10 percent after 400 passes; sensitive if relative cover was between 1 and 20 percent after 100 passes; and very sensitive if the plant was usually eliminated after 100 passes. Within each class plants are arranged from shrubs and subshrubs to graminoids, forbs, and miscellaneous.

Forbs are most divergent in their response. All the very sensitive species are forbs, but so are three of the six very resistant species. Tough leaves in a basal rosette or tuft and a woody base are characteristics that make some forbs particularly resistant. Taller, caulescent forbs are most sensitive. Schreiner (1974) found *Arenaria capillaris*, a species similar morphologically to *A. congesta*, to be resistant. Nagy and Scotter (1974) found *Xerophyllum tenax* to be resistant and *Thalictrum venulosum*, *Aster conspicuus*, and *Galium triflorum* to be highly sensitive.

The resistance of mosses has been noted many times (Schreiner 1974, 1980; Landals and Scotter 1974; Nagy and Scotter 1974; Holmes and Dobson 1976; Studlar 1980). Lichens have been found to be sensitive when trampled in high-elevation and high-latitude vegetation types (Schreiner 1974, 1980). In the midelevation types trampled in this study, lichens were only moderately susceptible to damage.

With only six exceptions, these fragility ratings (table 8) are comparable to ratings based on a comparison of species response on campsites in the Bob Marshall Wilderness and neighboring undisturbed control plots (Cole 1983). Compared to the study of existing campsites, this experimental study overestimates the fragility of *Smilacina stellata* and *Disporum trachycarpum*. These species appear to be highly resilient, recovering rapidly after disturbance from rhizomes. The experimental study underestimates the fragility of *Carex geyeri*, *Arctostaphylos uva-ursi*, *Linnaea borealis*, and mosses. Apparently, the initial resistance of these species declines when subjected to prolonged trampling. These hypotheses will be tested after following the response of these species to subsequent years of trampling.

EFFECT OF TRAMPLING ON MINERAL SOIL EXPOSURE

In addition to eliminating vegetation cover, trampling also can erode the surface organic horizons of the soil, exposing mineral soil beneath. Before trampling, all of the habitat types had a mean mineral soil exposure of 0 percent, although seven of the 34 subplots on the FESC-FEID type and one of the subplots on the PSME/SYAL type had traces of exposed mineral soil. The increase in exposure resulting from trampling was expressed simply as the percentage of exposure after trampling minus the percentage before—usually zero. No correction for changes on the control lanes was necessary because these lanes had no mineral soil exposure.

Table 9 shows the relationship between trampling intensity and increase in mineral soil exposure for each habitat type and for all types combined. Because most values were zeros, the distribution of values was so highly skewed that nonparametric statistics were used to draw inferences about the statistical significance of these results.

A Friedman two-way analysis of variance (Siegel 1956) suggested that increase in exposure differs both with amount of trampling and with habitat type ($p < 0.001$). Page's test for ordered alternatives based on Friedman rank sums was used to test whether or not mineral soil exposure increased with trampling. Multiple comparisons

Table 9.—The relationship between number of passes and percentage increase in mineral soil exposure for each habitat type and for all types combined[1]

Number of passes	Habitat type[2]												All types	
	ABLA/CLUN		ABLA/CLUN-VACA phase		ABLA/VACA		ABLA/XETE		PSME/SYAL		FESC-FEID			
	Mean	S.d.	Mean	S.d.	Mean	S.d.	Mean	S.d.	Mean	S.d.	Mean	S.d.	Mean	S.d.
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	1	1	—	—	—	—	+	1	+	1
40	—	—	—	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	+	1	3	5	—	—	1	2
80	—	—	—	—	—	—	—	—	—	—	+	+	+	2
100	—	—	—	—	—	—	2	5	1	4	1	2	1	3
200	—	—	—	—	+	1	—	—	—	—	—	—	+	+
300	—	—	1	4	1	4	2	9	4	8	+	1	1	5
400	—	—	—	—	—	—	1	4	3	6	—	—	1	3
600	—	—	—	—	—	—	1	1	7	11	3	9	2	7
800	—	—	—	—	—	—	—	—	1	4	3	5	1	3
900	—	—	—	—	3	9	4	5	15	22	+	1	4	11
1,200	—	—	—	—	6	16	1	1	8	9	3	4	4	8
1,600	—	—	—	—	—	—	1	1	14	21	13	14	6	12
Mean	0	0	0.5	3	0.8	4.6	0.9	3.7	3.5	9.4	1.3	4.5	1.4	5.6

[1] Increase in mineral soil exposure is percentage mineral soil exposure after trampling minus percentage mineral soil exposure before trampling. A + indicates less than 0.5 percent.

[2] Habitat types are:

ABLA/CLUN = *Abies lasiocarpa/Clintonia uniflora*
ABLA/CLUN-VACA = *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* phase
ABLA/VACA = *Abies lasiocarpa/Vaccinium caespitosum*
ABLA/XETE = *Abies lasiocarpa/Xerophyllum tenax*
PSME/SYAL = *Pseudotsuga menziesii/Symphoricarpos albus*
FESC-FEID = *Festuca scabrella—F. idahoensis.*

based on Friedman rank sums were used to identify which of the trampling treatments were different from the control and from each other and which habitat types differed in their response (Hollander and Wolfe 1973).

For all habitat types combined, exposure increased significantly ($p < 0.001$) as number of passes increased. The treatment of 100 passes and treatments of 300 passes and above resulted in significantly more exposure of mineral soil than on the control ($\alpha = 0.05$). Differences in exposure were very small; this is underscored by the result that none of the individual trampling treatments differed significantly.

For individual habitat types, mineral soil exposure increased significantly as trampling increased on the ABLA/XETE, PSME/SYAL, and FESC-FEID habitat types. Although increases were as great as 13 to 15 percent after some treatments, results were so erratic (refer to high standard deviations in table 9) that there were no statistically significant differences between treatments and control or among treatments for any individual habitat type.

The resistance of these habitat types to mineral soil exposure appears to be affected primarily by depth of the organic horizons and the slope of the plot perpendicular to the treatment lanes. Soil exposure was greatest on the PSME/SYAL habitat type, which had a slope of 20 to 25 percent. All of the other habitat types were almost flat. Walking perpendicular to this slope cut terraced paths into the slope, exposing more mineral soil than if there had been no slope. For the other types, those with the deepest organic horizons, ABLA/CLUN and ABLA/CLUN-VACA, had the least exposure; those with the shallowest horizons, ABLA/XETE and FESC-FEID, had the most. Despite how readily apparent these differences are in the field and from the results in table 9, the only statistically significant difference between habitat types ($\alpha = 0.05$) is that ABLA/CLUN experienced less mineral soil exposure than PSME/SYAL.

To generalize, 1,600 passes are sufficient to reveal a general tendency for increased trampling to lead to increased exposure of mineral soil. Increases are highly erratic, difficult to predict, and generally not very pronounced. This suggests that, in contrast to vegetation loss, there is considerable resistance to soil exposure and that it would take either prolonged trampling or much higher levels of trampling to cause pronounced increases in mineral soil exposure. This corroborates a study of existing campsites that found soil exposure to be one of only a few types of impact that only become serious after use of campsites exceeds low-use levels (Cole and Fichtler 1983).

EFFECT OF TRAMPLING ON SOIL COMPACTION

Penetration resistance, as measured with a pocket soil penetrometer, was used as a measure of soil compaction. Penetration resistance readings are affected by a number of soil characteristics, but particularly by differences in soil moisture. Because of this, a comparison of pre- and posttreatment readings would include a sizable component of change that was unrelated to the treatment itself. Therefore the measure of change used was simply the penetration resistance of the treatment subplot minus the mean penetration resistance of the control lane.

A two-way analysis of variance again showed that both number of passes and habitat type influenced increase in penetration resistance and that there was a significant interaction between these two main effects ($p < 0.001$). In this case, variances were made more homogeneous with a logarithmic (base 10) transformation. Figure 17 graphs the relationship between compaction and trampling intensity for each habitat type and table 10 shows the resistance of each habitat to each level of trampling.

It is clear that trampling generally increased penetration resistance; only a few values were negative. Moreover, with the exception of the ABLA/CLUN habitat type, there was a clear tendency for resistance to increase as trampling increased. As with vegetation loss, this relationship was a curvilinear one in which the increase in compaction caused by a given increment of trampling decreased as trampling increased. For most habitat types, the most rapid increase occurred with the first 50 to 75 passes. The rate of increase was less, but still rapid, up to 400 passes. Beyond this level of trampling the rate of increase was much less.

Pocket soil penetrometer readings are not very precise and are highly variable (Jones 1978). This variability, which could have been compensated for by making more observations, is probably a major source of the erratic nature of the increases in penetration resistance apparent in figure 17.

Another factor that contributed to the erratic nature of these increases is variability in amount of surviving vegetation on treatment lanes. Vegetation apparently cushions the impact of trampling, because compaction was usually less on lanes with high relative cover values. For example, the unexpectedly high penetration resistance value after 800 passes in ABLA/CLUN-VACA (fig. 17b) coincides with an unusually low relative cover value of 8 percent (fig. 10b).

Compaction from trampling was least pronounced on the ABLA/CLUN and ABLA/CLUN-VACA types. In fact, in the ABLA/CLUN type none of the treatments were significantly different ($\alpha = 0.05$) from the control. The least resistant types were ABLA/VACA and ABLA/XETE. Generally it appears that those types with the thickest organic horizons are least susceptible. Theoretically this would be expected because, in most situations, organic matter cushions the mineral soil from compaction (Lunt 1937; Lutz 1945; Lull 1959).

Differences between types in resistance to soil compaction were considerably less pronounced than differences in resistance to vegetation loss. Across the range of trampling from zero to 1,600 passes, no differences between habitat types explain as much of the variation in penetration resistance increase as differences in amount of trampling. In multiple regressions with pairs of habitat types and number of passes as independent variables and increase in penetration resistance as the dependent variable, the r^2 contribution of number of passes (0.15 to 0.50, depending upon which types were compared) was always higher than the r^2 contribution of habitat type (0.003 to 0.14).

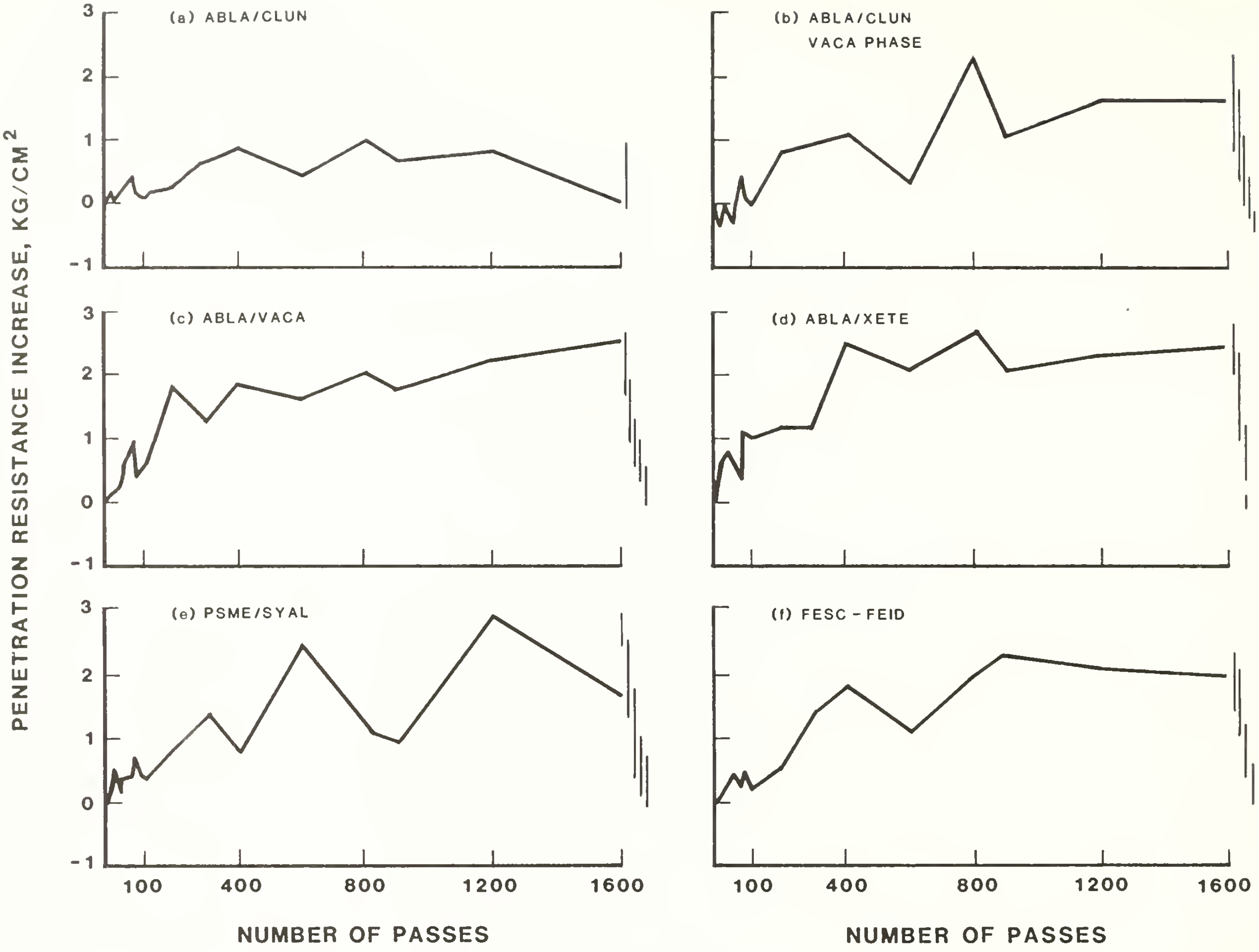

Figure 17.—The relationship between number of passes and increase in penetration resistance (treatment value minus control value). Lines at the right of each graph connect values that are not significantly different (Duncan's multiple range test, $\alpha = 0.05$).

Table 10.—Mean increase in penetration resistance (kg/cm^2) (treatment value minus control value) after various amounts of trampling for each habitat type and for all types combined[1]

Number of passes	Habitat type[2]						All habitat types
	ABLA/ CLUN	ABLA/CLUN-VACA phase	FESC-FEID	PSME/ SYAL	ABLA/ VACA	ABLA/ XETE	
5	0.18bc	−0.25a	0.01ab	0.06ab	0.18bc	0.59c	0.16
15	.03a	0a	.10a	.49a	.20a	.64a	.29
25	.21a	−.03a	.25a	.21a	.30a	.73a	.32
40	.23b	−.35a	.38b	.39b	.50b	.66b	.37
75	.36a	.40a	.21a	.44a	.96a	.35a	.47
80	.16ab	.05a	.38ab	.66bc	.43ab	1.04c	.52
100	.06ab	0a	.16ab	.35ab	.60bc	1.00c	.43
200	.28a	.85ab	.51a	.84ab	1.79b	1.16ab	.97
300	.64a	.94a	1.39a	1.35a	1.28a	1.14a	1.19
400	.83ab	1.10ab	1.78bc	.75a	1.91bc	2.53c	1.59
600	.43a	.33a	1.06ab	2.43c	1.65bc	2.10c	1.52
800	.93a	2.33a	1.93a	1.16a	2.08a	2.68a	1.89
900	.71a	1.05ab	2.28b	.98a	1.80ab	2.03ab	1.59
1,200	.81a	1.63ab	2.08b	2.89b	2.29b	2.31b	2.16
1,600	.03a	1.68b	1.93b	1.65b	2.58b	2.45b	1.89
All amounts	.38a	.63a	.93b	.94b	1.17bc	1.33c	.97

[1] Any two values in the same row followed by the same letter are not significantly different (Duncan's multiple range test, α = 0.05).

[2] Habitat types are:
ABLA/CLUN = *Abies lasiocarpa/Clintonia uniflora*
ABLA/CLUN-VACA = *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* phase
FESC-FEID = *Festuca scabrella-F. idahoensis*
PSME/SYAL = *Pseudotsuga menziesii/Symphoricarpos albus*
ABLA/VACA = *Abies lasiocarpa/Vaccinium caespitosum*
ABLA/XETE = *Abies lasiocarpa/Xerophyllum tenax.*

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Before discussing conclusions and management implications, it is important to reemphasize that these results apply to only the first-year effects of trampling. They are useful for understanding the initial effects of recreation use on undisturbed sites. The results presented here—as well as those of all the other experimental trampling studies reviewed—cannot be extended to sites where use occurs year after year. That will only be possible after evaluating the effects of several years of trampling and recovery.

The first-year results corroborated the following:

1. For most habitat types there is a curvilinear relationship between trampling intensity and both vegetation loss and soil compaction. The additional impact caused by heavier trampling decreases as trampling intensity increases. This has significant implications for managing the distribution of human use.

2. The grassland was much more resistant to vegetation loss than any of the forested habitat types. Of the forested types, those suffering the most cover loss were those with large proportions of erect, leafy-stemmed forbs. Mosses and *Xerophyllum tenax* (beargrass) were the major resistant plants in the forested types. Consequently, ABLA/XETE was the most resistant forested habitat type.

3. In contrast to vegetation loss and soil compaction, mineral soil was exposed only after a large amount of trampling. As surveys of existing campsites show (Cole 1982c), all but the most infrequently used recreation sites will suffer vegetation loss, but only the most frequently used sites will experience significant baring of mineral soil. This suggests that selecting a site with resistant vegetation is important at low to moderate use levels, but where use is heavy it would be better to select sites less prone to exposure of mineral soil—sites with relatively thick organic horizons and low surface erosion potential.

4. Variations in trampling frequency had considerably less effect on vegetation loss than the total amount of trampling, differences between habitat types, and even local variations in species distribution within habitat types. Consequently, trying to influence whether a given number of visits are concentrated in time or spread throughout the use season will, in most cases, have little effect on how much vegetation is lost.

The information generated from this study can be most usefully applied in deciding how to distribute use spatially in order to minimize impacts. As these results show, impact is dependent upon both amount of use and where that use occurs. These relationships are complicated by the fact that the importance of both differences in amount of use and differences between habitat types varies with use intensity. In the forested habitat types, differences in amount of use only affect vegetation loss profoundly if use is less than about 300 passes per season. At higher use levels, differences in amount of use have little effect on cover. Differences in the susceptibility of habitat types to vegetation loss, after one season of use, are most pronounced at use levels of 300 to 900 passes.

Managers can influence the spatial distribution of use in two ways that can reduce impact. First, they can influence the vegetation types on which people camp, and second, they can influence whether camping occurs on sites that have been used frequently, infrequently, or never before.

The results of this study show that, in the study area, camping will cause less vegetation loss in a grassland than in a forest. This corroborates the results of a study of existing sites in the Bob Marshall Wilderness (Cole 1983). If camping occurs in forest, it is best to camp in a type with lots of *Xerophyllum tenax*. If frequent use of sites is likely, sites might best be located in a forested type like ABLA/CLUN. The fragility of vegetation becomes irrelevant with heavy trampling because most vegetation is eliminated from any site. Nevertheless, the thick organic horizons of the ABLA/CLUN type make it less prone to mineral soil exposure and severe soil compaction.

The apparent effect of local differences in species composition on amount of vegetation loss suggests that care about where visitors walk, build a fire, and set up a tent can have a great influence on amount of impact. If visitors can recognize particularly fragile species (see table 8) and avoid trampling them, vegetation loss could be minimized. Again, this is only likely to be effective on infrequently used campsites.

For vegetation loss and soil compaction, aggregate impact in any local area—a concern for both the severity and areal extent of impact—will generally be minimized when use is directed to whichever site has already been most frequently used. The following example illustrates this point. After treatment, the 100-pass lane of the ABLA/CLUN type (a 16-ft^2 [1.5-m^2] area) loses 61 percent cover (table 4). The next increment of 100 passes will be less damaging if applied to the 100-pass lane rather than an unused lane. Two hundred passes on one lane would remove 74 percent cover over a 1.5-m^2 area—12 ft^2 (1.11 m^2) of vegetation would be lost; 100 passes each along two lanes would remove 61 percent cover over a 32-ft^2 (3-m^2) area—a loss of 20 ft^2 (1.83 m^2) of vegetation. In other words, less vegetation will be lost when use is concentrated on one site as opposed to being distributed over more sites.

The exception to this is the FESC-FEID grassland where it would be best to keep total use on any site below 1,200 passes. At this level of use, no cover loss occurs. Of course, trampling at this level year after year might cause pronounced changes. We will be in a position to evaluate this possibility after further seasons of trampling.

The curve relating mineral soil exposure to amount of use appears to be a straight line. That is, any incremental increase in use has about the same effect, regardless of how much use the site has already received. This suggests that aggregate impacts for mineral soil exposure will be about the same whether use is concentrated or spread among a number of sites.

Although impacts appear to usually be minimized by concentrating use on a few sites, minimizing amount of ecological change is only one goal of management. Esthetic concerns and the provision of opportunities for solitude and primitive and unconfined recreation are also important. It might be logical, for example, for management to decide that a campsite is acceptable if vegetation cover exceeds 50 percent and mineral soil exposure is less than 5 percent. We can see from tables 4 and 9 that to achieve this, use could be no more than 40 passes in ABLA/CLUN, 80 passes in PSME/SYAL, 100 passes in ABLA/CLUN-VACA, 150 passes in ABLA/VACA, 700 passes in ABLA/XETE, and 1,200 passes in FESC-FEID sites.

Obviously, to make such predictions useful it is necessary to convert number of passes into a unit of use managers can apply. This cannot be done exactly, but by using a number of assumptions and some observations of camping activities it is possible to develop a reasonable conversion.

I counted numbers of tramples associated with building a fire and cooking a simple meal. In one-half hour of meal preparation, one person took about 500 steps within the immediate cooking area—an area of about 100 ft^2 (10 m^2). From this, I estimated that in an overnight stay, one person would take a minimum of 1,500 steps in this area; 500 at breakfast, 500 at dinner, and 500 during the other hours in camp. A number of studies undertaken in diverse wildernesses (for example, Heberlein and Dunwiddie 1979; Lucas 1980; Leonard and others 1978) have shown that the most common party size is two and median and mean party size is usually three or four. If we take three as an average number, I would estimate a minimum of about 4,000 steps in the central 100 ft^2 (10 m^2) of the campsite. This is slightly less than 3 times 1,500 because of work-sharing in any cooking effort. Pressures exerted will be higher than this because impacts caused by standing, sitting, and lying are not included. Leney (1974) has shown that these activities do have a significant impact, although they are less destructive than moving about. Liddle (1975b) states, for example, that the vertical force applied by a standing man is about 2.8 lb/in^2 (200 g/cm^2) compared with a force of 800 lb/in^2 (57,000 g/cm^2) applied when in motion. Consequently, 4,000 steps per overnight stay by a typical party of three should be considered a conservative estimate.

The next problem is to relate this number of steps to number of passes in the lanes during the experiment. The treatments were administered in lanes that are 1 ft (0.3 m) wide and 16.4 ft (5 m) long. Most people took an average of seven steps in each lane, so each step occurs in a 1- by 2.3-ft (0.3- by 0.714-m) area (2.3 ft^2; 0.214 m^2). Therefore, during each pass, each 0.214-m^2 area is stepped on once. If we assume that 4,000 steps

(1 night's use) are equally distributed throughout the central 100 ft^2 (10 m^2) of the campsite, then each 0.214 m^2 area of the central campsite is trampled 87 times—the equivalent of 87 passes. This should be a conservative estimate, but let us assume that 75 to 150 passes will simulate the amount of trampling that occurs in 1 night of use by a typical party of three in the central 100 ft^2 (10 m^2) of a campsite. Peripheral parts of the campsite would receive less use.

We tested these estimates by measuring vegetation response to actual camping on two of these vegetation types. Two people spent 1 night each on previously undisturbed sites near the trampling plots in the ABLA/CLUN and ABLA/XETE types. Cover measurements, similar to those taken on trampling plots, were taken on nine quadrats systematically dispersed in a 100-ft^2 (10-m^2) area around a fire ring and nine around a tent site in each type. Measurements were taken before and after the 8-week trampling period; the night of camping occurred in the middle of this period.

Relative cover around the fire ring after 1 night of camping was 45 percent in ABLA/CLUN and 78 percent in ABLA/XETE. From table 4 and figure 10, this level of impact corresponds most closely with 100 passes in each of these types. The relative cover of the most abundant species around the fire ring was comparable to that found after 75 to 200 passes, depending on the species. Thus, the estimate of 75 to 150 passes as simulating the effect of a typical party in the central part of the campsite appears realistic.

Relative cover around and under the tent was 92 percent in ABLA/CLUN and 95 percent in ABLA/XETE. In both cases this corresponds most closely with the effect of 15 passes. For the most abundant species, relative cover was comparable to that found after 5 to 25 passes, depending on the species. Thus, the effect of 5 to 25 passes appears to simulate the effect of a typical party around the tent.

A large party of, say, 12, although four times as large, would probably not trample any given area four times as much. Per capita impacts on any square meter will be less than with a small party because tasks are shared. I estimate that the central area would be trampled three times as much as with a party of three, an intensity equivalent to about 250 to 400 passes. Because people in a large party must spread out more, however, this high level of trampling on the campsite occurs over a much larger area (i.e., the effects of the 250 to 400 passes will apply to an area perhaps two to three times as large as 100 ft^2 [10 m^2]).

Using these estimates, acceptable use frequencies for the average party are: no use for ABLA/CLUN; 1 night of use for PSME/SYAL, ABLA/CLUN-VACA, and ABLA/VACA; 5 to 8 nights for ABLA/XETE; and 10 to 15 nights for the FESC-FEID grassland. Campsites used by large parties would only be acceptable in ABLA/XETE (2 to 3 nights of use) and FESC-FEID (3 to 4 nights of use).

Clearly, such predictions should be treated cautiously and conservatively. Cumulative changes from prolonged trampling will also probably be more severe, making desirable use frequencies even lower. Nevertheless, the estimates do compare favorably with measures of vegetation loss on campsites in similar vegetation types receiving estimated amounts of use (Cole and Fichtler 1983).

In addition to corroborating the appropriateness of management suggestions derived from earlier studies of existing campsites (Cole 1982c, 1983; Cole and Fichtler 1983), this study provides more precise quantification of use levels, for individual habitat types, at which dispersal or concentration is likely to be appropriate. Except in the grassland, concentration is always better at minimizing ecological change, particularly vegetation loss. If objectives such as allowing no more than 50 percent vegetation loss are developed, however, dispersal can be desirable, particularly where use levels are not high and vegetation is resistant (for example, in the FESC-FEID and ABLA/XETE habitat types).

Exactly what these use thresholds are will depend upon stated objectives. The previous example, using an objective of no more than 50 percent vegetation loss and 5 percent soil exposure, shows how this can be done. But there is no magic in these objectives. Managers may want to maintain more or less cover than this. The point is that we are getting closer to a point where we can predict quantitatively the effects of alternative use configurations on campsite conditions.

In assessing the applicability of these results elsewhere, it is worth reiterating that the FESC-FEID grassland is the most resistant vegetation type and ABLA/XETE is the most resistant forested type studied experimentally. The graphs in figures 1 and 10 can be used in areas with similar vegetation types to assess the likely effects of initial use of undisturbed sites. For some unstudied ecosystem types, such as deserts, however, there are no available estimates of the effects of given amounts of use.

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APPENDIX 1: SOIL PROFILES

Soil Profile at the *Abies lasiocarpa/Clintonia uniflora* Habitat Type Plot

Oi 11–9 cm (4.3–3.5 in).

Oe 9–0 cm (3.5–0 in).

E 0–6 cm (0–2 in). Grayish brown (10YR 5/2) silt loam, light gray (10YR 7/1) dry; weak very fine to medium crumb structure; very friable (moist), nonsticky and nonplastic (wet); many very fine and fine, common medium, and few coarse roots; noncalcareous; slightly acid; clear smooth boundary.

Bo 6–31 cm (2–12 in). Dark brown (7.5YR 4/4) silt loam, pink (7.5YR 7/4) dry; weak very fine to fine and moderate medium crumb structure; very friable to friable (moist), sticky and plastic (wet); common fine and few medium to coarse roots; noncalcareous; slightly acid; abrupt smooth boundary.

2Bt 31–75 cm (12–30 in). Dark gray (10YR 4/1) silty clay loam, light gray (10YR 7/1) dry; moderate very fine to fine subangular blocky structure; friable (moist), slightly sticky and plastic (wet); common fine roots; clay skins common thin to common thick on ped faces; noncalcareous; slightly acid; abrupt smooth boundary.

3C 75–80 cm (30–32 in). Grayish brown (10YR 5/2) sandy loam, light gray (10YR 7/1) dry; moderate very fine to fine subangular blocky structure; very friable to friable (moist), slightly sticky and slightly plastic (wet); very few smooth ped faces (possibly stress cutans); noncalcareous; slightly acid; abrupt smooth boundary.

4Btb 80–97+ cm (32–38+ in). Reddish brown (10YR 5/3) silty clay, light gray (10YR 7/1) dry; strong coarse angular blocky and massive structure; very firm (moist), very sticky and plastic (wet); few fine roots; clay skins common thin to common thick on ped faces; noncalcareous; slightly acid.

Location: SE¼ of SW¼ of Sec. 36, T. 17 N., R. 13 W.
Classification: (Andeptic) Eutric Glossoboralf, coarse-loamy over fine, mixed, frigid
Parent material: Ash over lacustrine sediments
Physiographic position: On stream terrace, in slight concavity at the foot of the side slope
Elevation: 4,400 feet
Slope: 0–4 percent
Remarks: I called horizon Bo ash because it had a distinctive color and boundary and a high silt content and apparently low bulk density (felt light and fluffy) compared to the underlying horizon. I have assigned this soil to the Glossoboralf great group because it probably has a frigid temperature regime and less than 60 percent base saturation in the argillic horizon. However, it has no albic tongues into the argillic horizon, characteristic of a Glossoboralf, and furthermore, horizon Bo is apparently ash. Therefore, I have assigned this soil to a new subgroup: (Andeptic) Eutric Glossoboralf. Colors are for the moist soil unless otherwise indicated.

Soil Profile at the *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* Phase Habitat Type Plot

Oi 6–4.5 cm (2.4–1.8 in).

Oe 4.5–0 cm (1.8–0 in).

A 0–10 cm (0–4 in). Dark yellowish brown (10YR 3/4) cobbly sandy loam, light yellowish brown (10YR 6/4) dry; weak very fine to fine crumb structure; very friable (moist), nonsticky and nonplastic (wet); many very fine to fine and few medium roots; noncalcareous; very strongly acid; 85 percent angular gravel to cobbles; clear wavy boundary.

CA 10–45 cm (4–18 in). Strong brown (7.5YR 4/6) cobbly sand, brown (7.5YR 5/4) dry; very weak very fine crumb and single grain structure; loose (moist), nonsticky and nonplastic (wet); many very fine to fine and few medium roots; noncalcareous; very strongly acid; 95 percent angular gravel to cobbles; abrupt wavy boundary.

C 45–80+ cm (18–31+ in). Strong brown (7.5YR 4/6) cobbly sand, strong brown (7.5YR 5.5/6) dry; single grain; loose (moist), nonsticky and nonplastic (wet); common very fine to fine and few medium roots; noncalcareous; 90 percent angular gravel to cobbles.

Location: SW¼ of SE¼ of Sec. 20, T. 16 N., R. 12 W.
Classification: Typic Udorthent, sandy-skeletal, mixed, frigid
Parent material: Glacial outwash
Physiographic position: Broad, flat terrace (about 1/2 mile wide)
Elevation: 4,200 feet
Slope: 0–3 percent
Remarks: Colors are for the moist soil unless otherwise indicated.

Soil Profile at the *Abies lasiocarpa/Vaccinium caespitosum* Habitat Type Plots

Oi 3.5–3 cm (1.4–1.2 in).

Oe 3–0 cm (1.2–0 in).

E 0–2 cm (0–1 in). Dark grayish brown (10YR 4/2) cobbly fine sandy loam, light gray (10YR 7/2) dry; very weak very fine crumb structure; loose (moist), nonsticky and slightly plastic (wet); common very fine and few fine roots; noncalcareous; strongly acid; 10 percent angular to subrounded gravel, 10 percent subrounded cobbles; abrupt smooth boundary.

Bo 2–16 cm (1–6 in). Dark yellowish brown (10YR 4/4) cobbly silt loam, light yellowish brown (10YR 6/4) dry; moderately weak fine crumb structure; very friable (moist), slightly sticky and slightly plastic (wet); common very fine and fine, few coarse roots; noncalcareous; slightly acid; 10 percent angular to subrounded gravel, 10 percent subrounded cobbles; clear smooth boundary.

Bo2C1 16–31 cm (6–12 in). Yellowish brown (10YR 5/4) stony silt loam, very pale brown (10YR 7/3) dry; very weak very fine crumb and moderate very fine to fine subangular blocky structure; very friable and friable (moist), slightly sticky and slightly plastic (wet); few very fine and fine roots; noncalcareous; slightly acid; 10 percent subrounded gravel, 30 percent subrounded cobbles, and 20 percent subrounded stones; clear wavy boundary.

2C1 31–49 cm (12–19 in). Light brownish gray (10YR 6/2) stony sandy loam, white (10YR 8/2) dry; very weak fine crumb and moderate very fine subangular blocky structure; loose to friable (moist), nonsticky and nonplastic (wet); few very fine roots restricted to rock faces; noncalcareous; medium acid; 10 percent subrounded gravel, 30 percent subrounded cobbles, and 20 percent subrounded stones; abrupt smooth boundary.

2C2 49–95+ cm (19–37+ in). Light brownish gray (10YR 6/2) stony sandy loam, white (10YR 7.5/2) dry; moderate fine to medium angular blocky structure; firm (moist), nonsticky and nonplastic (wet); no roots; many, fine, discontinuous, horizontal, tubular pores within blocks; noncalcareous; medium acid; 10 percent subrounded gravel, 30 percent subrounded cobbles, and 20 percent subrounded stones.

Location: NW¼ of NE¼ of Sec. 19, T. 17 N., R. 15 W.

Classification: Andic Dystrochrept, loamy-skeletal, mixed, frigid

Parent material: Ash over glacial till, outwash, and lacustrine deposits

Physiographic position: Hummocky raised bench above glacially-carved valley

Elevation: 4,400 feet

Slope: 0–7 percent

Remarks: I called the Bo horizon an ash layer because it had a distinctive color and boundary and a high silt content (estimated at 60 percent), low coarse fragment content, and apparently low bulk density (felt light and fluffy) compared to adjacent horizons. Colors are for the moist soil unless otherwise indicated.

Soil Profile at the *Abies lasiocarpa/Xerophyllum tenax* Habitat Type Plots

Oi 0.7–0.5 cm (0.3–0.2 in).

Oe 0.5–0 cm (0.2–0 in).

A 0–4 cm (0–2 in). Very dark grayish brown (10YR 3/2) silt loam, dark grayish brown (10YR 4/2) dry; moderately weak very fine to fine crumb structure; very friable (moist), slightly sticky and nonplastic (wet); many very fine and few fine roots; noncalcareous; very strongly acid; 5 percent angular to subrounded gravel; abrupt smooth boundary.

Bo 4–28 cm (2–11 in). Dark yellowish brown (10YR 4/6) silt loam, light yellowish brown (10YR 6/4) dry; very weak very fine crumb structure; very friable to loose (moist), nonsticky and nonplastic (wet); common very fine, few fine and medium roots; noncalcareous; slightly acid; 3 percent angular gravel, 12 percent subrounded gravel; abrupt wavy boundary.

2C 28–81+ cm (11–32+ in). Brown (7.5YR 5/4) cobbly sand, light brownish gray (10YR 6/2) dry; single grain; loose (moist), nonsticky and nonplastic (wet); common very fine and few fine roots; noncalcareous; slightly acid; 10 percent angular and rounded gravel, collectively, and 75 percent subrounded gravel and cobbles, collectively.

Location: SE¼ of SW¼ of Sec. 36, T. 17 N., R. 13 W.

Classification: Andic Dystrochrept, sandy-skeletal, mixed, frigid

Parent material: Ash over glacial outwash

Physiographic position: Broad stream terrace

Elevation: 4,400 feet

Slope: 0–2 percent

Remarks: I called horizon Bo ash because it had a distinctive color and boundary and a high silt content (estimated at 55 percent), low coarse fragment content, and apparently low bulk density (felt light and fluffy) compared to the underlying horizon. Colors are for the moist soil unless otherwise indicated.

Soil Profile at the *Pseudotsuga menziesii/Symphoricarpos albus* Habitat Type Plots

Oi 6–4.5 cm (2.4–1.8 in).

Oe 4.5–0 cm (1.8–0 in).

A 0–9 cm (0–4 in). Very dark grayish brown (10YR 3/2) finely gravelly silt loam, light brownish gray (10YR 6/2) dry; moderately weak very fine crumb structure; very friable (moist), slightly sticky and nonplastic (wet); many very fine, few fine, and common medium roots; noncalcareous; very strongly acid; 30 percent angular gravel; clear wavy boundary.

E 9–29 cm (4–11 in). Brown (10YR 5/3) finely gravelly loam, light gray (10YR 7/2) dry; moderately weak very fine to fine crumb structure with a few moderately weak very fine subangular blocks; very friable (moist), slightly sticky and nonplastic (wet); many very fine, few fine, and common medium roots; noncalcareous; medium acid; 40 percent angular gravel; clear wavy boundary.

2E 29–42 cm (11–17 in). Brown (10YR 5/3.5) cobbly sandy loam, very pale brown (10YR 7/3) dry; moderately weak to moderate very fine to fine subangular blocky structure; friable (moist), nonsticky and nonplastic (wet); common very fine, fine, and coarse roots; noncalcareous; medium acid; 25 percent angular gravel, 25 percent channery sandstone, and 20 percent subrounded cobbles; gradual irregular boundary.

2Bt1 42–90 cm (17–35 in). Yellowish brown (10YR 5/4) cobbly clay, light yellowish brown (10YR 6/4) with common fine to medium, faint yellowish brown (10YR 5/4) mottles dry; moderate and strong very fine to medium angular blocky structure; firm to extremely firm (moist), sticky and plastic (wet); many thin clay skins on ped and rock faces; common very fine, few fine and medium roots all restricted to rock and ped faces; noncalcareous; slightly acid; 25 percent angular gravel, 25 percent channery sandstone, and 20 percent subrounded cobbles, at 70 cm changing to 10 percent angular gravel, 15 percent channery sandstone, and 55 percent subrounded cobbles; gradual irregular boundary.

2Bt2 90−99+ cm (35−39+ in). Yellowish brown (10YR 5/4) cobbly clay marginal to sandy clay, very pale brown (10YR 7/3) dry; moderate very fine to fine angular blocky structure; firm (moist), slightly sticky and plastic (wet); common thin clay skins on ped and rock faces; few very fine roots restricted to rock faces; noncalcareous; slightly acid; 10 percent angular gravel, 15 percent channery sandstone, and 55 percent subrounded cobbles.

Location: NE¼ of NW¼ of Sec. 32, T. 16 N., R. 12 W.

Classification: Eutric Glossoboralf, clayey-skeletal, mixed, frigid

Parent material: Colluvium over glacial till mixed with residual sandstone

Physiographic position: Side slope about 100 m above a stream terrace

Elevation: 4,200 feet

Slope: 20−25 percent to the SW

Remarks: High bulk density below 42 cm may restrict water movement. Sandstone flagstones in the 2Bt2 horizon could be cut with a spade and broke easily in the hand. Colors are for the moist soil unless otherwise indicated.

Soil Profile at the *Festuca scabrella-F. idahoensis* Habitat Type Plots

Oe 3−0 cm (1.2−0 in).

A 0−19 cm (0−7 in). Black (10YR 2/1) gravelly silt loam, very dark grayish brown (10YR 3/2) dry; very weak medium crumb and moderate fine to medium subangular blocky structure; very friable to friable (moist), nonsticky and slightly plastic (wet); many very fine and few fine roots; noncalcareous; neutral; 45 percent angular to subrounded gravel; clear wavy boundary.

Bw 19−27 cm (7−11 in). Very dark grayish brown (10YR 3/2) gravelly loam, brown (10YR 4.5/3) dry; moderate fine to medium subangular blocky structure breaking to very fine subangular blocks; very friable to friable (moist), slightly sticky and slightly plastic (wet); common very fine and few fine roots; noncalcareous; neutral; 45 percent angular to subrounded gravel; clear wavy boundary.

CBw 27−41 cm (11−16 in). Dark grayish brown (10YR 4/2) gravelly loam, brown (10YR 5/3) dry; moderately weak fine crumb and moderately weak fine subangular blocky structure; very friable (moist), slightly sticky and slightly plastic (wet); many very fine and common fine roots; noncalcareous; neutral; 45 percent angular to subrounded gravel; clear irregular boundary.

Ck1 41−73 cm (16−29 in). Dark grayish brown (10YR 4/2) gravelly silt loam, brown (10YR 5/3) dry; very weak medium crumb structure breaking to single grain; very friable (moist), slightly sticky and slightly plastic (wet); many very fine and common fine roots; bulk of soil noncalcareous with a few white flecks strongly effervescent; neutral; 35 percent angular to subrounded gravel; abrupt wavy boundary.

Ck2 73−95+ cm (29−37+ in). Dark brown (10YR 4/3) gravelly loam, brown (10YR 5.5/3) dry; very weak fine subangular blocky structure breaking to very fine subangular blocks and single grains; friable (moist), slightly sticky and slightly plastic (wet); common very fine and few fine roots; violently effervescent pockets in the soil matrix and white coatings on the bottoms of coarse fragments; 50 percent gravel and 10 percent angular cobbles.

Location: SE¼ of SE¼ of Sec. 15, T. 15 N., R. 14 W.

Classification: Typic Haploboroll, loamy-skeletal, mixed, frigid

Parent material: Glacial till

Physiographic position: Spur ridge about 50 feet wide, with side slopes of about 15 percent

Elevation: 4,400 feet

Slope: 0−2 percent

Remarks: Colors are for the moist soil unless otherwise indicated.

APPENDIX 2: MEAN COVER AND FREQUENCY VALUES

Mean Cover and Frequency Values for Species on the *Abies lasiocarpa/Clintonia uniflora* Habitat Type Plot[1]

Species	Cover	Frequency
	------ Percent	------
SHRUBS AND SUBSHRUBS		
Amelanchier alnifolia	2	7
Berberis repens	22	99
Linnaea borealis	2	21
Pachistima myrsinites	5	50
Rhamnus alnifolia	1	6
Rosa gymnocarpa	1	7
Rubus idaeus	1	3
Rubus parviflorus	2	15
Spiraea betulifolia	8	59
Symphoricarpos albus	7	28
GRAMINOIDS		
Bromus vulgaris	2	38
Calamagrostis rubescens	+	1
Elymus glaucus	+	1
FORBS		
Adenocaulon bicolor	8	56
Arnica cordifolia/A. latifolia	24	87
Aster conspicuus	1	18
Calypso bulbosa	+	1
Clintonia uniflora	9	47
Disporum trachycarpum	+	3
Epilobium angustifolium	1	21
Fragaria vesca	2	29
Fragaria virginiana	3	49
Galium triflorum	2	44
Osmorhiza chilensis	3	62
Pyrola chlorantha	+	7
Smilacina stellata	18	84
Thalictrum occidentale	36	96
Veratrum viride	1	3
Viola orbiculata	4	62
Xerophyllum tenax	2	4
MOSSES		
(mainly *Rhytidiopsis*)	3	16
Mean total plant cover	93	

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[1] Cover is the mean percent cover of sixty-eight 2- by 5-dm subplots. Frequency is the percent of these subplots in which the species was found. A + indicates cover less than 0.5 percent.

Mean Cover and Frequency Values for Species on the *Abies lasiocarpa/Clintonia uniflora-Vaccinium caespitosum* Habitat Type Plot[1]

Species	Cover	Frequency
	------ Percent	------
SHRUBS AND SUBSHRUBS		
Amelanchier alnifolia	1	3
Arctostaphylos uva-ursi	8	62
Berberis repens	19	84
Linnaea borealis	45	97
Lonicera utahensis	3	13
Rhamnus alnifolia	+	1
Rosa gymnocarpa	+	1
Spiraea betulifolia	11	57
Symphoricarpos albus	1	4
Vaccinium globulare	5	19
GRAMINOIDS		
Bromus vulgaris	2	16
Calamagrostis rubescens	13	76
Carex concinnoides	1	10
Carex geyeri	2	12
FORBS		
Antennaria racemosa	4	32
Arnica cordifolia	1	3
Aster conspicuus	+	1
Aster foliaceus	1	21
Campanula rotundifolia	+	1
Chimaphila umbellata	9	82
Cirsium hookeriana	+	1
Clintonia uniflora	+	3
Disporum trachycarpum	+	7
Fragaria vesca	1	6
Fragaria virginiana	8	76
Galium boreale	3	54
Galium triflorum	+	4
Goodyera oblongifolia	+	6
Hieracium albiflorum	1	9
Osmorhiza chilensis	2	40
Pyrola secunda	+	4
Senecio pseudaureus	+	1
Smilacina stellata	1	4
Thalictrum occidentale	2	19
Viola adunca	+	7
Mean total plant cover	92	

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[1] Cover is the mean percent cover of sixty-eight 2- by 5-dm subplots. Frequency is the percent of these subplots in which the species was found. A + indicates cover less than 0.5 percent.

Mean Cover and Frequency Values for Species on the *Abies lasiocarpa/Vaccinium caespitosum* Habitat Type Plots[1]

Species	Plot 1		Plot 2	
	Cover	Frequency	Cover	Frequency
	Percent			
SHRUBS AND SUBSHRUBS				
Arctostaphylos uva-ursi	22	93	4	38
Berberis repens	+	1	—	—
Linnaea borealis	—	—	+	6
Rosa acicularis	2	16	1	7
Spiraea betulifolia	5	46	2	18
Vaccinium caespitosum	33	99	47	100
GRAMINOIDS				
Calamagrostis rubescens	15	91	11	88
Carex concinnoides	+	10	+	4
Carex geyeri	3	25	1	3
FORBS				
Achillea millefolium	2	29	+	7
Antennaria racemosa	—	—	3	13
Arnica cordifolia	1	3	1	7
Calochortus apiculatus	+	1	+	1
Campanula rotundifolia	—	—	+	6
Chimaphila umbellata	—	—	1	9
Fragaria virginiana	+	1	5	63
Hedysarum occidentale	11	68	1	7
Hieracium albiflorum	1	13	1	12
Lupinus argenteus	11	63	7	43
Melampyrum lineare	6	57	6	88
Penstemon procerus	+	1	+	6
Viola adunca	+	3	+	1
Xerophyllum tenax	13	37	20	65
MOSSES (mainly *Brachythecium*; some *Polytrichum* and *Rhytidiadelphus*)	13	74	32	93
LICHENS (mainly *Cladonia*; some *Peltigera*)	5	60	5	50
Mean total plant cover	90		90	

[1] Cover is the mean percent cover of sixty-eight 2- by 5-dm subplots. Frequency is the percent of these subplots in which the species was found. A + indicates cover less than 0.5 percent.

Mean Cover and Frequency Values for Species on the *Abies lasiocarpa/Xerophyllum tenax* Habitat Type Plots[1]

Species	Plot 1		Plot 2	
	Cover	Frequency	Cover	Frequency
	Percent			
SHRUBS AND SUBSHRUBS				
Berberis repens	—	—	+	1
Lonicera utahensis	+	1	—	—
Pachistima myrsinites	2	9	+	3
Spiraea betulifolia	1	15	1	15
Vaccinium globulare	22	81	8	31
Vaccinium scoparium	55	100	52	100
GRAMINOIDS				
Calamagrostis rubescens	1	19	1	10
Carex concinnoides	3	29	2	35
Carex geyeri	+	6	+	6
FORBS				
Chimaphila umbellata	—	—	1	6
Fragaria virginiana	—	—	+	1
Goodyera oblongifolia	1	6	+	3
Hieracium albiflorum	1	38	1	32
Melampyrum lineare	2	57	+	12
Xerophyllum tenax	22	53	35	84
MOSSES (mainly *Brachythecium* and *Dicranum*; some *Polytrichum*)	56	100	34	100
LICHENS (mainly *Cladonia*; some *Peltigera*)	27	97	39	97
Mean total plant cover	93		94	

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[1] Cover is the mean percent cover of sixty-eight 2- by 5-dm subplots. Frequency is the percent of these subplots in which the species was found. A + indicates cover less than 0.5 percent.

Mean Cover and Frequency Values for Species on the *Pseudotsuga menziesii/Symphoricarpos albus* Habitat Type Plots[1]

Species	Plot 1		Plot 2	
	Cover	Frequency	Cover	Frequency
	Percent			
SHRUBS AND SUBSHRUBS				
Amelanchier alnifolia	2	7	3	10
Berberis repens	10	82	22	99
Linnaea borealis	1	4	—	—
Rosa gymnocarpa	1	13	1	6
Spiraea betulifolia	16	74	12	60
Symphoricarpos albus	16	35	4	19
GRAMINOIDS				
Calamagrostis rubescens	34	96	28	87
Carex concinnoides	1	3	—	—
Carex geyeri	—	—	1	4
FORBS				
Achillea millefolium	+	1	—	—
Arnica cordifolia	13	93	18	96
Aster conspicuus	3	29	2	21
Aster foliaceus	—	—	+	3
Castilleja miniata	+	3	—	—
Clematis columbiana	+	1	+	3
Disporum trachycarpum	+	6	+	4
Epilobium angustifolium	—	—	+	1
Erythronium grandiflorum	1	15	+	3
Fragaria vesca	+	1	1	4
Fragaria virginiana	8	93	10	82
Galium boreale	—	—	+	1
Goodyera oblongifolia	1	18	+	1
Hedysarum occidentale	1	4	—	—
Hieracium albiflorum	+	4	+	4
Lithospermum ruderale	—	—	+	1
Lupinus wyethii	+	4	+	10
Osmorhiza chilensis	2	57	+	6
Pyrola secunda	+	3	—	—
Smilacina racemosa	—	—	+	1
Thalictrum occidentale	5	47	8	54
Viola adunca	1	19	+	6
MOSSES				
(mainly *Brachythecium*)	9	31	3	19
Mean total plant cover	81		81	

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[1] Cover is the mean percent cover of sixty-eight 2- by 5-dm subplots. Frequency is the percent of these subplots in which the species was found. A + indicates cover less than 0.5 percent.

Mean Cover and Frequency Values for Species on the *Festuca scabrella-F. idahoensis* Habitat Type Plots[1]

Species	Plot 1		Plot 2	
	Cover	Frequency	Cover	Frequency
	Percent			
SHRUBS AND SUBSHRUBS				
Berberis repens	+	7	—	—
Rosa acicularis	1	9	—	—
GRAMINOIDS				
Agropyron spicatum	11	47	—	—
Carex filifolia	8	44	+	3
Carex rossii	2	15	—	—
Carex vallicola	+	3	—	—
Festuca idahoensis	27	88	43	100
Festuca scabrella	76	100	58	100
Koeleria cristata	4	32	10	81
Poa scabrella	2	16	—	—
FORBS				
Achillea millefolium	8	65	14	93
Antennaria microphylla/ A. umbrinella	+	3	2	37
Arenaria congesta	—	—	9	88
Arnica sororia	3	32	1	19
Balsamorhiza sagittata	2	9	—	—
Campanula rotundifolia	1	10	+	10
Castilleja lutescens	—	—	+	4
Chrysopsis villosa	—	—	5	49
Clematis hirsutissima	—	—	2	15
Collinsia parviflora	+	9	—	—
Crepis atrabarba	—	—	1	22
Eriogonum umbellatum	+	3	1	4
Gaillardia aristata	—	—	+	6
Galium boreale	1	15	—	—
Geranium viscosissimum	5	25	—	—
Hieracium albertinum	—	—	2	21
Lithophragma parviflora	+	4	+	1
Lithospermum ruderale	+	1	1	1
Lomatium macrocarpum	—	—	1	13
Lupinus sericeus	9	79	26	100
Penstemon confertus/P. procerus	2	12	1	9
Potentilla arguta	+	1	—	—
Potentilla gracilis	5	34	+	1
Solidago missouriensis	10	49	7	74
Mean total plant cover	95		94	

---

[1] Cover is the mean percent cover of sixty-eight 2- by 5-dm subplots. Frequency is the percent of these subplots in which the species was found. A + indicates cover less than 0.5 percent.

Cole, David N. Recreational trampling effects on six habitat types in western Montana. Research Paper INT-350. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 43 p.

This study examined the response of six vegetation types in western Montana to experimental trampling. All of the forest types showed a curvilinear relationship between amount of trampling and loss of vegetation cover, loss of plant species, and soil compaction. A grassland was more resistant to vegetation loss. These results can be used to evaluate the likely effects of different use levels on campsites and to identify the most durable locations for campsites.

KEYWORDS: ecological impact, trampling, wilderness, backcountry management, habitat types

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**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-351

September 1985

Costs of Managing Nontimber Resources When Harvesting Timber in the Northern Rockies

**Robert E. Benson
Michael J. Niccolucci**

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ANALYSIS OF VARIANCE
                       DF       SUM OF SQUARES       MEAN SQUARE
REGRESSION              7           9430.00995        1347.14428
RESIDUAL              179           5147.94181          28.75945

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VARIABLE                   B          SE D       95% CONFDNCE  INTRVL B

OBJFOOD              1.51892        .86371        -.18545      3.22329
RDWID               -2.42929       1.05312       -4.50742      -.35117
PAVEHAUL              .38058        .02437         .332 8       .4286
RDGRAD                .80485        .17870         .45
WPDE                 1.69679        .98355
LOGM                  .22787        .05645
UNPAVE                .50194        .04326
(CONSTANT)          -4.93842       2.55665
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RESEARCH SUMMARY

When National Forest Timber is sold, land managers are required to protect other forest resources such as wildlife, soil and water, and scenic qualities. Measures taken to protect nontimber resources can raise administrative costs, lower the quantity of timber sold, and can reduce stumpage receipts. The costs of sale administration and the reduction in timber harvested can be readily derived from accounting and planning records. But little information is available on how much nontimber resources cost in terms of stumpage receipts. To provide such information, some 187 timber sales were studied on seven National Forests in the Northern Region between 1975 and 1981. The study focused on the questions: How do nontimber requirements and objectives affect, first, the appraisal costs allowed in deriving the stumpage value? And second, how do they affect the margin the purchaser bids over and above the estimated stumpage value?

Timber sale folders provided extensive data on characteristics of the sale area and harvesting techniques, and also on general nontimber requirements and specific activities made to meet nontimber goals. Stepwise regression analysis was used to identify those nontimber concerns that were significant in logging costs and bid margins.

These analyses estimated that, in terms of 1980 dollars, the average logging cost allowance for nontimber considerations was $18 per thousand board feet (M bd ft), and bid margins were reduced by another $8/M bd ft, for a total cost of $26/M bd ft for meeting nontimber resource management concerns. This $26 represents about 18 percent of the average logging cost of $144; or in terms of stumpage values, about one quarter of the average $107/M bd ft purchasers paid for the sales used in the analyses.

We made alternative analyses with different assumptions as to how nontimber concerns are considered, but the resulting estimates were similar, ranging from $24 to $26/M bd ft for meeting nontimber goals.

Protecting soil and water and wildlife resources, particularly deer and elk, were the most important nontimber goals. Road construction, sale layout, and harvesting practices were the activities most frequently modified to protect nontimber resources. There was, however, considerable variation among timber sales as to the nontimber provisions undertaken and the costs incurred for them. Furthermore, current and future timber sales may differ from those in the sample. As management policies change and timber harvesting practices evolve, more experience and efficiency is gained in meeting nontimber objectives in timber sales.

Costs of Managing Nontimber Resources When Harvesting Timber in the Northern Rockies

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Michael J. Niccolucci

INTRODUCTION

On National Forests, the management of all resources is closely tied to the timber harvesting program. Nontimber resources—forage, wildlife, water, and scenic qualities—may require measures to protect them from degradation or to improve and enhance their value (Schuster and others 1984). The past two decades have seen a substantial increase in provisions to protect the environment and to manage the National Forests for all resources. There has also been a growing concern about management costs and effective use of public money.

The Forest and Rangeland Renewable Resources Planning Act (1974) directs the Forest Service to identify costs and benefits, and to conduct economic analyses of the management of both timber and nontimber resources. Often, however, information needed for such analyses is lacking. Gathering information on costs and values and incorporating these into management planning and programs have involved a substantial (and continuing) effort by planners, managers, researchers, and special study teams.

Much of the forest land in the Northern Rockies is on moderately steep land where harvesting must be designed to protect soil and water. Scenic and recreational values are important, too, and virtually all forest land is habitat for many wildlife species. It is generally believed that, all other things being equal, measures taken to protect or enhance nontimber resources will raise harvesting costs per unit of timber cut. These cost increases in turn lower receipts in dollars per thousand board feet ($/M bd ft) received for the timber. Clearly, "How much lower?" is an important question, but it is not easily answered.

Three categories of costs influence how nontimber concerns affect Forest Service timber sales: administrative costs, opportunity costs, and actual logging costs. Administrative costs are those incurred in preparing and overseeing the timber sale. Budgets and accounting records used by the Forest Service may show direct expenditures for a nontimber resource, but do not necessarily reflect the total effect the activity or requirement has had on harvesting costs, particularly at the project level, such as a timber sale. For example, the timber sale records may show costs of a wildlife biologist's time and supplies for identifying and marking snags for den or nest trees as a rather small, direct wildlife expenditure. But protecting those snags while yarding logs and treating slash may prove to be more costly than marking them. The costs allowed for yarding may therefore be unusually high, but the timber sale appraisal would not indicate why.

Opportunity costs are costs generated by forgoing certain actions that would maximize income. For example, if a patch of timber is not harvested because it is on an elk calving ground, or a strip of timber is left for streamside protection, the value of the timber not harvested is an opportunity cost. Both administrative costs and opportunity costs are important considerations in evaluating nontimber costs, but they are not addressed in this study. Costs analyzed in this study are those associated with logging and related activities. Because costs incurred in logging are reflected in the stumpage value received by the Forest Service, any cost increases due to nontimber considerations may result in reduced stumpage values. Thus reduced stumpage value is one means by which the Forest Service pays for maintaining nontimber resources.

Nontimber goals can profoundly influence stumpage values. Stumpage value is based on the wholesale price of lumber (or other product) less the costs of manufacturing the product and costs of logging—getting the logs from the stump to the mill. If a nontimber objective is expected to increase logging costs, an appropriate allowance is made.

Nontimber requirements can also affect what purchasers actually bid for stumpage. The appraised stumpage value has been estimated by subtracting manufacturing and logging costs from lumber selling price. But in competing for the sale the purchaser may bid more than this value to get the sale. The difference between the appraised value and the actual bid is the bid premium. If the purchaser feels that nontimber provisions will actually cost him more than the appraisal has allowed, he may reduce his bid difference. This reduction is actually a cost to the seller (Forest Service) because it reduces receipts. (Conversely, if the purchaser thinks that the appraisal allowance for nontimber requirements is greater than what it may actually cost him, he may increase his bid difference.)

There are differences in these two aspects of costs that should be noted in the analyses that follow. Allowances for logging costs include all of the principal factors that logically affect logging costs: characteristics of the timber sale area, logging methods, and various nontimber considerations. Analysis of bid differences is based on the timber sale characteristics, logging methods, and nontimber considerations. Other factors not related to logging may also affect bid difference. These include purchaser's expectation of markets, the urgency of his need for logs, and his bidding strategy relative to other buyers. Although we recognize the importance of such factors, appropriate data were not available, and thus could not be included in the analysis.

STUDY SCOPE AND METHODS

Records of recent timber sales were analyzed to determine whether the variations in harvesting costs are related to the presence (or absence) of activities and requirements to manage nontimber resources. The study covered seven National Forests in western Montana and northern Idaho. A random sample of 187 sales conducted between 1975 and 1981 comprised the data base. Sales during this period conformed to laws and administrative regulations requiring consideration of nontimber values. The sales were selected from those of about 2 million bd ft and larger (smaller sales are less likely to include a full range of nontimber resources). The timber sale files at each Forest Supervisor's office were examined and extensive data were recorded for the analysis. Data included descriptive information (size, silvicultural characteristics, and so on) and qualitative and quantitative measures of various operations, methods, and nontimber resources involved. All costs had been adjusted to 1980 dollars for use in a separate study (Merzenich 1985), using the GNP implicit price deflator.

Measuring Costs

The logging costs analyzed in this study include most of those on the timber appraisal forms used in sale preparation. Costs are expressed as dollars per thousand board feet ($/M bd ft), the form in which costs are estimated in timber appraisals. The logging costs from the 187 sample sales were as follows:

	Mean	Range
	$/M bd ft	
Felling and bucking	22.86	12.59 to 59.14
Skidding and loading	46.32	23.35 to 90.00
Haul	23.42	7.04 to 58.99
Road maintenance	5.48	0.15 to 31.37
Temporary roads	1.03	0 to 15.02
Specified roads	32.52	0 to 112.45
Slash disposal	12.40	0.95 to 41.60

The actual cost incurred by the timber operator may be different from the appraisal cost allowed, but the actual costs are not part of the sale record, and may not be specifically documented even by the operator. The appraised cost is mainly of interest here because it reflects how the appraiser has accounted for the various activities and requirements. The following tabulation shows average lumber price, logging costs, and bid premium for the sales analyzed:

Lumber price, log scale	$340/M bd ft
−manufacturing, profit, misc.	−156
−logging	−144
Appraised stumpage value	$ 40
Purchaser's bid	$107
Bid difference (bid minus indicated)	$ 67

The seven logging cost items and the bid difference are the central subject of the analyses that follow.

Explanatory Variables

Linear regression was used to estimate the relationship between costs and various activities and requirements on the sale. The general model used is

$$Y = \alpha_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \epsilon$$

where Y is the cost in $/M bd ft for different phases of harvesting as indicated in the timber sale appraisal allowance; X_i represents the various sale characteristics, activities, and requirements that are related to these costs; b_i is the regression coefficient, and its estimation is the focus of this study; α_o is the constant; and ϵ is the error term. Four kinds of variables were expected to affect harvest costs (a complete listing of variables is in appendix B, tables 16−20):

1. **Site variables** are features of the sale that are mostly given in the sale; on a given site they cannot be altered. The six site variables used in the analysis and their mean values for the sample sales are:

Variable	Mean
Volume per acre harvested, M bd ft	16.0
Logs/M bd ft (a reflection of tree size)	18.0
Roads	
Specified road construction (miles)	6.3
Road reconstruction (miles)	5.6
Hauling	
Paved haul distance (miles)	23.0
Unpaved haul distance (miles)	13.4

2. **Harvest decision variables** are features that are part of every sale and are primarily related to the cutting and removing of logs. Such variables may reflect concerns for timber resources, nontimber resources, or both. The harvest decision variables and their mean values from the sample sales are:

Variable	Mean
Cutting method	
Clearcut (including seed tree and right of way)	38.3% of area
Partial cut—individual tree mark, shelterwood, etc.	59.0% of area
Group selection	2.4% of area
Yarding method	
Tractor	62.9% of area
Jammer	18.1% of area
Skyline	17.7% of area
Total area harvested	540 acres
Size of cutting unit	50 acres
Number of cutting units	15 units

3. **Nontimber variables** are requirements, objectives, plans, and methods for managing nontimber resources. Such variables are usually described in qualitative terms in narrative statements in the sale folder. We analyzed such statements and sorted the main considerations into one or more categories of nontimber resources. These were:

Soil
Water
Fish
Wildlife
Recreation
Visual
Cultural
Range

Within each of these categories a present/absent (1,0) coding was used to designate the type and extent to which the resource was considered. Three categories of information were used for each of the eight nontimber resources:

Resource Plan—Indicates a nontimber resource was taken into account in the timber sale. For some resources, this was further defined as to type from more specific statements, such as a specific visual quality objective (VQO) or a species of wildlife.

Objective—Indicates the objective intended for a resource, such as protecting a wildlife travel zone, meeting a water budget constraint, and so on.

Activity—Indicates in general terms how the objectives are to be accomplished, such as by modifying sale plans and layout, modifying road layout or construction, and so on.

In total, 102 general nontimber requirements (NTR's) were initially measured. In the analysis some variables were combined where this would improve the data base and enhance the analysis. Factor analysis was used as an intermediate step in selecting the final NTR's used in each logging cost model. All NTR's were measured as being present (1) or absent (0). The mean value for all sample sales therefore indicates the proportion of observations (timber sales) in which the particular NTR item was present. Some examples of these variables, with their code label and proportion of sample sales in which they occurred, are:

	Code	Percent of sales
Recreation considered in plan	RECPLAN	88
Logging modified to protect soil	SOACT3	19
Wildlife plan for deer and elk	WPD&E	66
Visual quality objective specified	VQO	42

4. **Specific activities variables**. Although the NTR's described above reflect the considerations given to each nontimber resource, they do not always indicate specifically what activities were undertaken. We therefore gathered information for a group of variables that we called specific activities. Such variables describe exactly what was done to modify the various phases of the harvesting operation. Some of these activities or requirements may serve several purposes; for example, a strip of timber left along a stream may protect water quality and fish habitat, prevent soil erosion along the streambank, and provide a travel way and cover for wildlife. The nontimber resource involved may not be specified, but the activity and the phase of logging cost it may affect are described. Some examples of these variables and their mean values in the sample sales are:

Example	Mean
Whole-tree logging required	Present on 10% of sales
Directional felling required	67% of harvest area
Maximum road grade allowed	9.2% slope
Seeding trails and landings	22.9 acres per sale
Shaping or feather edge on unit	4.6% of harvest area

These variables were used in their original form (absent [0], present [1], or as continuous scale for measurements such as acres, percentage, etc.). Some of the individual specific activity variables were combined where appropriate.

Regression Models

The variables discussed above were tested in various combinations in the stepwise regression models

$$Y = \alpha_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \epsilon$$

where X_i's are the variables selected to be tested in a given cost model (felling, hauling, and so on) and b_i the estimated coefficient. Therefore, each variable, X, has its own b_i that represents the estimated change in cost, Y, as X is increased or decreased. Many of the nontimber considerations we expected would increase costs, so β_i was hypothesized to be positive (that is greater than zero): for example, protecting snags for wildlife might be expected to increase slash disposal costs (avoiding knocking over when piling slash). Other variables were expected to decrease costs, and therefore hypothesized to be negative (less than zero). For example, as volume per acre increases, skidding costs per thousand board feet are expected to decrease, all other things being equal. Symbolically, the hypotheses tested are:

1. When we expected a variable to increase costs,

$H_o : \beta_i = 0$
$H_a : \beta_i > 0$

2. When we expected a variable to decrease costs,

$H_o : \beta_i = 0$
$H_a : \beta_i < 0$

3. When we did not know whether a variable would increase or decrease costs,

$H_o : \beta_i = 0$
$H_a : \beta_i \neq 0$

Hypotheses 1 and 2 were tested at $\alpha = 0.05$ (one-tail test); hypothesis 3 at $\alpha = 0.10$ (two-tail test). Although the statistical and mathematical procedures of regression analyses are relatively straightforward, the results (identifying significant explanatory variables and estimating coefficients) can be affected by the way in which the regression models are constructed and the computational procedures specified. If the objective was to predict appraisal costs, the regression analyses would be aimed at developing the most accurate prediction, using the fewest and simplest explanatory variables. As noted earlier, however, the objectives of this study were to analyze the effect of nontimber variables and to derive the best estimate of how these affect costs.

In this study we assumed the "best estimate" model to be one in which any of the variables that could potentially affect costs were tested for significance. The large number of variables included in the study and a fairly large data base raise the possibility that regression analysis will produce spurious relationships—that is, mathematically and statistically significant, but illogical from the real-world standpoint. In building the models we tried to screen candidate variables to avoid this problem. These screened explanatory variables (site, decision, specific activities, and nontimber variables) were used in the analyses. Using standard stepwise regression procedures, the best estimate model computed the b coefficient and standard errors for each significant variable.

In typical multiple linear regression models, the question of range and variability of estimated coefficients is handled through confidence intervals computed from the standard error. This procedure was used in this study (Appendix A), but we also assessed the range of estimates by using different models that represent alternative approaches or philosophies to assessing the effects of nontimber variables on costs. These alternative approaches tend to make estimates of the cost of nontimber provisions (the b_i's) as large or as small as possible, thereby setting reasonable limits to the size of these costs. If two variables are totally independent of one another with regard to costs, then their estimated b coefficients will not change regardless of the analytical model used.

One point of view is that certain site characteristics are part of every sale and therefore their effects on cost should always be included first in the analysis. This approach was taken in one analysis by first "locking in" selected site variables and then allowing other variables to enter in a regular stepwise manner. Analytically, when this is done the variation explained by the site variables is first removed, and the nontimber variables can explain only the variation in cost that remains. We hypothesized that this would reduce the effect of nontimber concerns as measured by the estimated b coefficients, and we called it the "minimize nontimber" model.

An opposite point of view is that, regardless of site characteristics involved, the real concern is for the effects of nontimber considerations and that these costs can properly be measured only if the effects of site variables are removed from the analysis. This approach was taken in an analysis that excluded site variables from the model. This was termed the "maximize nontimber" model, because when site variables are excluded all variation in costs is attributed to the nontimber concerns and thus their estimated b coefficients would potentially be larger.

The above regressions were checked for violations of the assumptions that are the basis of the linear stochastic regression model. Examples of some of the assumptions that were checked are:

1. The variance of ϵ (error term) is constant
2. The error ϵ has a normal distribution
3. The explanatory variables are not perfectly linearly correlated
4. The assumption of linearity is true.

Plotting techniques and various "diagnostics" were used to validate the models. These techniques are explained in various texts (Koutsoyiannis 1979; Belsley and others 1980; Draper and Smith 1981).

In presenting the results in the next section, our discussion focuses primarily on the best estimate model, and the variables and their coefficients from the others—maximize or minimize nontimber—are discussed relative to the best estimate model.

RESULTS

In this section we present the results of the cost model regressions and discuss the variables that are significantly related to cost. The models are presented in more or less the chronological order of harvesting activities.

Table 1.—Felling and bucking cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
LOGM	# logs	0.779	(0.051)	0.779	(0.051)	[2]	
Decision							
GPSEL	area	.066	(.029)	-.066	(.029)	—	
Special activity							
WHOT	0,1	2.909	(1.215)	-2.909	(1.215)	—	
FELLO	% area	-.021	(.008)	-.021	(.008)	0.022	(0.012)
ONTR	0,1	3.783	(1.166)	3.783	(1.166)	4.694	(1.761)
Nontimber							
SOACT3	0,1	2.326	(.946)	2.326	(.946)	2.744	(1.421)
VQO	0,1	—		—		2.191	(1.140)
Constant		9.826	(1.146)	9.826	(1.146)	22.378	(1.178)
R^2		.603		.603		.104	
s.e of model		4.967		4.967		7.456	

[1] See text for definition of variables.

[2] Indicates this variable forced out of this model

Felling and Bucking Cost Model

The average appraised cost allowance for felling and bucking was $22.86/M bd ft and ranged from $12.59 to $59.14/M bd ft. The explanatory variables are summarized in table 1 and are listed in the following order: site, decision, specific activity, and nontimber resource.

SITE VARIABLE

Logs per M bd ft (LOGM).—Logs (16.4 ft) per M bd ft is recognized as an important cost determinant in many phases of logging. Its b coefficient was +0.779 in the best estimate model, indicating an increase of one log per thousand board feet "causes" an increase of about $0.78/M bd ft in felling and bucking costs. "Causes" is used in the logical sense that more logs require more labor, and so on; in a statistical sense the proper description is that the changes in both logs/M bd ft and costs are positively related.

HARVEST DECISION VARIABLE

Group selection (GPSEL).—In the best estimate model each 1 percent increase of group selection cutting in the sale area reduced felling and bucking costs about $0.06/M bd ft (b = −0.066). Group selection generally involves large, old-growth trees that have a large volume per stem, which reduces costs of felling and bucking. The coefficient was the same in the minimize nontimber model, and was not significant in the maximize nontimber model.

SPECIFIC ACTIVITIES VARIABLES

Whole-tree logging (WHOT).—When whole-tree logging was specified, costs were reduced by about $2.91/M bd ft (b = −2.909). In this method the sawyer only fells the tree and thus costs of limbing and bucking are eliminated from this phase. This may, of course, increase costs at the log landing or in slash disposal. The coefficient was the same in the minimize nontimber model; this requirement was not, however, significant in the maximize nontimber model.

Directional felling (FELLO).—Directional felling was measured in percentage of sale area in which it was required; it reduced costs by about $0.02/M bd ft for each 1 percent of area where it was required (b = −0.021 in best and minimize models). This is usually specified to facilitate yarding and to reduce damage to soil and residual trees. It apparently is also associated with slightly lower felling and bucking costs because it usually involves larger, old-growth trees whose additional volume offsets any increased labor involved.

Other nontimber requirements (ONTR).—Miscellaneous specific activities undertaken on the sale (ONTR) increased felling and bucking costs by about $3.78/M bd ft (b = 3.783) in the best and minimize models. When the site variable LOGM was forced out in the maximize nontimber model, the coefficient increased to 4.694. Miscellaneous other requirements were present on about 12 percent of the sales and included such things as special closures, installing sediment traps, use of flagpersons, and debris removal.

GENERAL NONTIMBER REQUIREMENTS (NTR'S)

Logging modified to protect soil (SOACT3).—When the timber sale plan modified logging activities to protect soil, the best estimate and minimize models predict that costs are increased by about $2.33/M bd ft (b = 2.326); the maximize model predicts $2.74 (b = 2.744). Usually soil protection measures involve yarding and roading activities, but there is apparently some secondary effect also on felling and bucking.

Visual quality objective (VQO).—If a visual quality objective had been specified for the sale, the maximize nontimber model predicts that felling and bucking costs would increase by about $2.19/M bd ft (b = 2.191); this was not significant in either the best estimate or minimize models. The reasons for this relationship are not identified, but it may reflect efforts to shape edges, reduce slash visibility, and so on; however, this variable was significant only in the maximize model that has forced out LOGM, the most important single cost factor.

DISCUSSION OF FELLING AND BUCKING COSTS

Table 1 reflects the similarity of the various alternative models for estimating the effect of different variables on felling and bucking costs. The best estimate and minimize nontimber models are identical. The maximize nontimber model has fewer explanatory variables, and these indicate a much larger effect of nontimber considerations. As stated previously, the objective was to estimate the maximum effect of nontimber considerations when all variations in cost were attributed to nontimber considerations.

"How much do nontimber considerations cost?" One answer is shown in figure 1. Recognizing that costs allowed for felling and bucking varied from $12/M bd ft to $59/M bd ft, this variability is explained primarily by site characteristics, in this case LOGM. The remaining

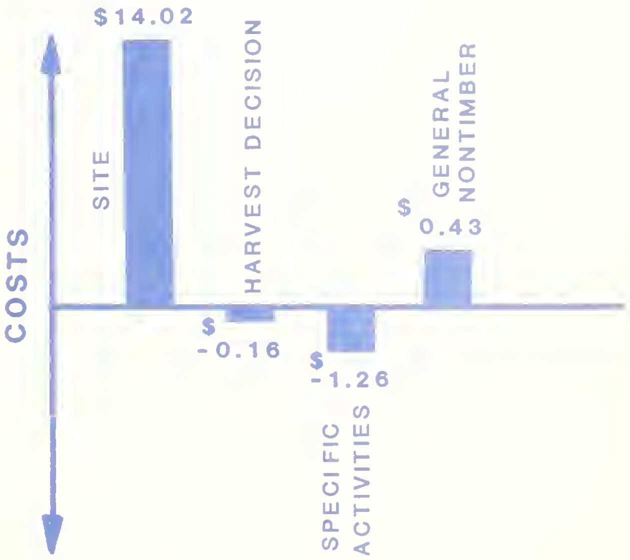


Figure 1.—Average contribution to felling and bucking costs by groups of variables, $/M bd ft.

variability is explained by requirements that directly or indirectly reflect nontimber considerations. This is based on the mean values—the average cost components of the sample sales. In the best estimate model, the constant ($9.83), plus the site variable LOGM, $14.02 (18 logs on average sale × 0.779 = 14.02) total $23.85/M bd ft. Because the average cost allowed was $22.86, this indicates that the net effect of all the other variables on the average sale is to slightly reduce felling and bucking costs. When the site variable LOGM is forced out in the maximize nontimber model and only nontimber-related variables remain, the net effect on the average sale is to add $0.48/M bd ft (average cost $22.86 minus the constant $22.38 = +$0.48). This suggests that usually nontimber considerations have little effect on felling and bucking costs.

Skidding and Loading Cost Model

The average appraised allowance cost for this item was $46.32/M bd ft, and ranged between $23.35 and $90/M bd ft. The variables that were significant in this model are summarized in table 2.

SITE VARIABLES

Logs per M bd ft (LOGM).—Costs increased by about $0.80/M bd ft for each additional LOGM in the best estimate model (b = 0.798). This is an expected relationship; increasing the number of pieces raises the costs of skidding and loading.

Volume per acre (VOL/A).—This variable in effect reduced costs by about $0.23/M bd ft (b = −0.230) for each increase of 1 M bd ft/acre. This reflects that less area has to be covered to skid a given volume of logs.

HARVEST DECISION VARIABLES

Skyline area (SKYA).—This variable indicated a $0.23/M bd ft increase in cost for each 1 percent increase in area skyline logged (b = 0.226). The coefficient was slightly higher in the minimize and maximize models, but these small differences are not statistically significant. This relationship is expected because skyline yarding is a relatively expensive yarding system.

Tractor log area (TLOGA).—The estimated effect of a 1 percent increase in tractor log area is a decrease of $0.15/M bd ft on cost (b = −0.153), again an expected effect because tractor logging is less expensive. This variable was not significant in the maximize model.

SPECIFIC ACTIVITIES VARIABLES

Corridor width (CORWID).—When corridor width is constrained (measured as present or absent), costs of skidding and loading are increased by $3.94/M bd ft (b = 3.941). Generally this requirement specified a corridor narrower than usual be used to protect residual leave-trees or understory; this variable was not significant in either the maximize or minimize models.

GENERAL NONTIMBER REQUIREMENTS (NTRS)

Soil plan (SOPLAN); logging modified to protect soil (SOACT3).—If the timber sale planning indicated consideration of soil protection, costs were increased by about $4.77/M bd ft (b = 4.771), and if logging activities were specifically modified to protect soil, skidding and loading costs are estimated to increase by another $3.47/M bd ft (b = 3.468). Making provisions for soil protection probably affects skidding more than any other phase, because factors such as road spacing, type of yarding, and restrictions on season of yarding are commonly used for soil protection and are directly related to off-road transportation costs. These two nontimber variables had slightly different coefficients in both the minimize and maximize models, but the differences were not significant.

Miscellaneous other wildlife (WLOTH).—The protection or enhancement of wildlife habitat other than food and cover (travel areas, calving grounds, wallows, and so

Table 2.—Skidding and loading cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
LOGM	number	0.798	(0.097)	0.755	(0.097)	[2]	
VOL/A	M bd ft	−.230	(.079)	.236	(.079)	[2]	
Decision							
TLOGA	% area	−.153	(.026)	−.142	(.026)	—	
SKYA	% area	.226	(.032)	.262	(.029)	0.279	(0.028)
Specific activity							
CORWID	0,1	3.941	(1.598)	—		—	
Nontimber							
SOPLAN	0,1	4.771	(1.870)	5.662	(1.862)	4.924	(2.128)
SOACT3	0,1	3.468	(1.577)	3.827	(1.594)	3.559	(1.919)
WLOTH	0,1	3.291	(1.514)	3.348	(1.537)	4.322	(1.813)
Constant		34.60	(3.107)	34.36	(3.152)	35.22	(2.092)
R^2		.609		.595		.399	
s.e. of model		8.04		8.15		9.89	

[1] See text for definition of variables.
[2] Indicates this variable forced out in this model.

on) was estimated to increase costs by $3.29/M bd ft (b = 3.291). In these special areas, skidding requirements such as full suspension of logs or no entry with tractors (necessitating winching) would increase costs.

DISCUSSION OF SKIDDING AND LOADING COSTS

Skidding and loading costs ranged from $23 to $90/M bd ft. As with felling and bucking, LOGM was again an important site variable and, along with volume per acre, accounted for about $10.68 of the average costs (fig. 2). Harvest decisions on type of logging method used, skyline or tractor, were also important. This was reflected by the general nontimber requirements (NTRS) SOPLAN and SOACT3, which accounted for $5.48/M bd ft on the average. The specific activity variable CORWID also relates to protecting the site and added $1.04/M bd ft on the average. Providing for nontimber resources therefore accounted for $6.52 ($5.48 +$1.04)/M bd ft of the total skidding and loading cost of $46.32/M bd ft.

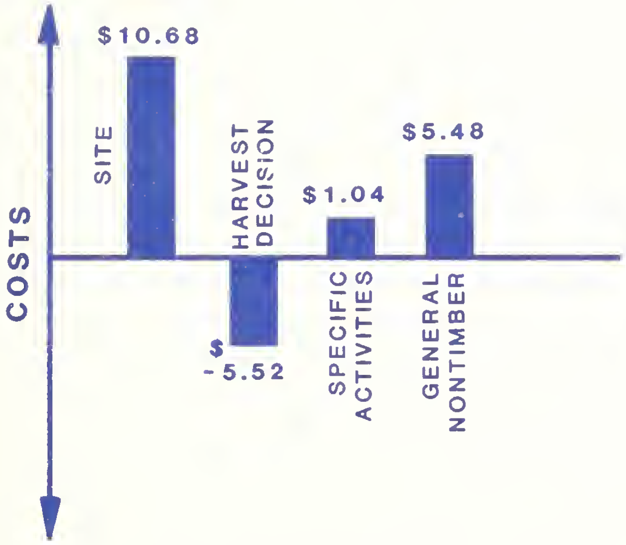


Figure 2.—Average contribution to skidding and loading costs by groups of variables, $/M bd ft.

While analyzing the data, many other constraints and provisions were tested as candidate variables. Individually they did not constitute a pattern that was statistically significant, but the general nontimber variables SOPLAN, SOACT3, and WLOTH can probably be viewed as variables that may indirectly reflect the importance of other "nitty gritty" requirements that are more directly tied to skidding costs.

Hauling Cost Model

The average appraised cost for hauling was $23.42/M bd ft and ranged between $7.04 and $58.99. Explanatory variables and their coefficients are shown in table 3.

SITE VARIABLES

Paved haul (PAVEHAUL) and unpaved haul (UNPAVEHAUL).—These two variables, which together represent hauling distance, were the most significant and, as might be expected, accounted for most of the variation in haul costs. Costs increased about $0.38/M bd ft for each additional paved mile (b = 0.381) and $0.50/M bd ft for each unpaved mile (b = 0.502).

Logs per M bd ft (LOGM).—Costs were increased by about $0.23/M bd ft for each additional LOGM (b = 0.228). Smaller logs have less board-foot scale per unit of log weight, and this apparently is taken into account in haul costs.

SPECIFIC ACTIVITIES VARIABLES

Road grade (RDGRADE).—This variable indicated that costs increased by about $0.80/M bd ft for each 1 percent

Table 3.—Hauling cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
PAVEHAUL	mile	0.381	(0.024)	0.381	(0.024)	[2]	
UNPAVEHAUL	mile	.502	(.043)	.502	(.043)	[2]	
LOGM	number	.228	(.056)	.228	(.056)	[2]	
Specific activity							
RDGRADE	% slope	.805	(. 9)	.805	(.179)	0.984	(0.271)
RDWID	0,1	−2.429	(1.053)	−2.429	(1.053)	—	
Nontimber							
WLFOOD	0,1	1.519	(.864)	1.519	(.864)	2.270	(1.290)
WPD&E	0,1	1.697	(.983)	1.697	(.983)	—	
WLTRAVEL	0,1	—		—		7.376	(2.583)
SOPLAN	0,1	—		—		−4.140	(1.778)
CULPLAN	0,1	—		—		3.161	(1.335)
Constant		−4.938	(2.556)	−4.938	(2.556)	14.159	(2.985)
R^2		.647		.647		.164	
s.e. of model		5.36		5.36		8.20	

[1] See text for definition of variables.
[2] Indicates this variable forced out in this model.

increase in allowable road grade (b = 0.805). The average road grade specified was 9 percent—minimum 4 percent, maximum 15 percent—so the potential effect on any given sale is considerable. The estimated effect appears even higher (b = 0.984) when nontimber is maximized, but this is not significantly different from the best estimate.

Road width (RDWID).—The usual road width specified is bunk width plus 4 ft. If a different width was specified it usually resulted in wider roads, which in turn were estimated to reduce hauling costs by about $2.43/M bd ft (b = −2.429). This probably means that increasing road width may reflect other variables (not measured) that would contribute to lower haul costs, such as more favorable alignment, flatter terrain, and higher speed limits.

GENERAL NONTIMBER REQUIREMENTS (NTR'S)

Wildlife plan for deer and elk (WPD&E).—If a general plan for protecting wildlife was part of the timber sale plan, appraisal hauling costs were raised an estimated $1.70/M bd ft (b = 1.697). A wildlife plan includes many items that could affect hauling: layout of cutting units, location of roads, seasonal restrictions, closures, and others.

Wildlife food (WLFOOD).—If a specified objective in the sale was to protect or enhance wildlife food (mainly for deer and elk), appraisal hauling costs were further increased by about $1.52/M bd ft (b = 1.519). The reason for this is not clear, but wildlife concerns probably call for less direct routing, narrower roads, and road closures or other restrictions that could cumulatively lead to greater hauling costs.

Wildlife travel zones (WLTRAVEL), soil plan (SOPLAN), and cultural plan (CULPLAN).—These three general nontimber variables were not significant in the best estimate model but did enter as significant when the important site variables were excluded in the maximize nontimber model. Their importance should therefore be viewed with some reservations.

Protecting wildlife travel zones was estimated to increase hauling costs by $7.38/M bd ft (b = 7.376) in the maximize model. The reason is probably similar to that for providing wildlife food: concern for wildlife indicates various road-related constraints that restrict hauling. The data, however, did not clearly show how this variable was related to haul costs; therefore the relationship should be considered speculative.

Soil plan (SOPLAN) was also significant only in the maximize model and lowered haul cost by $4.14/M bd ft (b = −4.140) when soil protection was a consideration. This may indicate that raising road standards and maintenance to protect soils also reduces hauling costs.

If the sale included considerations for a cultural plan, hauling costs were estimated to be increased $3.16/M bd ft (b = 3.161). Cultural plans include a variety of concerns, both historical and current, and in the case of hauling would usually involve closures, safety measures, or similar requirements.

DISCUSSION OF HAULING COSTS

In examining the hauling costs (fig. 3), it is apparent that the site variables PAVEHAUL, UNPAVEHAUL, and LOGM account for much of the average costs (nearly $20). Two road structure-related specific activities variables, RDWID and RDGRADE, account for another $7. The road specifications probably reflect both soil/water considerations and other vehicle-related considerations like truck hauling speeds, recreation vehicle safety, and so on. At any rate, the two road-related variables account for about $6.95/M bd ft (average values of sample sale multiplied by the best estimate coefficients) and the two wildlife considerations another $1.82/M bd ft.

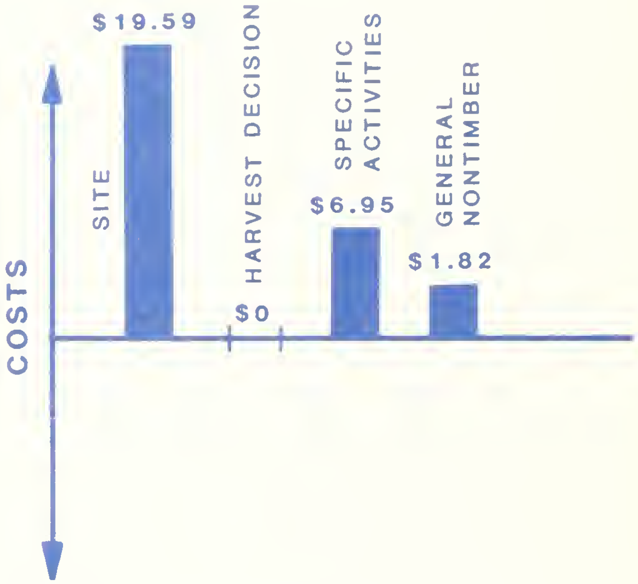


Figure 3.—Average contribution to haul costs by groups of variables, $/M bd ft.

Road Maintenance Cost Model

The average appraisal allowance for road maintenance was $5.48/M bd ft, and ranged between $0.15 and $31.37. The significant variables are presented in table 4.

SITE VARIABLES

Unpaved haul (UNPAVEHAUL).—Maintenance costs were increased by about $0.21/M bd ft for each mile of unpaved hauling (b = 0.206) in the best estimate model. Unpaved roads must be graded and cleared of debris, and ditches and culverts kept in working order. The effect was virtually the same in the minimize nontimber model.

Paved haul (PAVEHAUL) and logs per M bd ft (LOGM).—These two variables were forced into the minimize model for reasons cited earlier, but were not significant in the best estimate model. We hypothesized that more logs per thousand (LOGM) could affect allocation of transportation costs in the appraisal, but this variable

Table 4.—Road maintenance cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
PAVEHAUL	mile	—		0.022	(0.019)	—	
UNPAVEHAUL	mile	0.206	(0.030)	.223	(.033)	—	
LOGM	number	—		.004	(.043)	—	
Specific activity							
SNOW	0,1	—		—		-1.505	(0.885)
CLOSBAR	number	—		—		.142	(.081)
ORA	0,1	1.573	(.806)	1.560	(.824)	2.779	(.876)
Nontimber							
CULPLAN	0,1	1.833	(.658)	1.850	(.675)	1.577	(.742)
VQO	0,1	1.291	(.620)	1.196	(.636)	—	
Constant		.634	(.708)	-.082	(1.318)	3.960	(.692)
R^2		.280		.278		.113	
s.e. of model		4.06		4.14		4.51	

[1] See text for definition of variables

—Indicates this variable forced out of this model

was significant only when forced in. The coefficient was <\$0.01/M bd ft, which is not significantly different from 0. Maintenance costs increased about \$0.02/M bd ft for each additional mile of paved haul (PAVEHAUL) but were not significant in the best estimate model.

SPECIFIC ACTIVITIES VARIABLES

Special road activities (ORA).—In some sales, special maintenance is required above and beyond the standard provisions; when present, these requirements (constraints on equipment, special vegetation treatment, and so on) added \$1.57/M bd ft to appraised maintenance costs in the best estimate model (b = 1.573). In the maximize nontimber model this was increased to b = 2.780, which is notably higher.

Closure barriers (CLOSBAR) and snow removal required (SNOW).—We hypothesized that these requirements would affect maintenance costs, but they proved significant only in the maximize model. For each closure barrier, maintenance costs were estimated to increase \$0.14/M bd ft (b = 0.142). This probably results from the cost of keeping barriers intact and possibly reflects the existence of conditions that are even more fragile and difficult to maintain (cleaning ditches, resurfacing), which leads to closures. In the maximize nontimber model, snow removal was a significant variable and was estimated to reduce maintenance costs by \$1.50/M bd ft (b = −1.505). The reason for this is not clear, but to the extent that this indicates winter logging, hauling on frozen and snowpacked roads may result in less damage to road surfaces than spring or summer hauling and could reduce maintenance needs. This should be considered a speculative relationship.

GENERAL NONTIMBER REQUIREMENTS (NTR'S)

Cultural resources plan (CULPLAN).—If the sale accommodated cultural resource considerations, the effect was estimated to be an additional \$1.83/M bd ft (b = 1.833). Because cultural concerns include both historical and current factors, this primarily reflects additional maintenance provided in the interest of people use (such as residences, popular recreation areas, and so on). The effect of this variable is less in the maximize model (b = 1.577), an unexpected result, but statistically the coefficients are not significantly different.

Visual quality objective (VQO).—If the sale area had specified a visual quality objective, the effect was to add \$1.29/M bd ft (b = 1.291) to maintenance. Although this relationship was not specifically explained, it probably indicates that where visitor use activities are accommodated in a cultural plan, a visual quality objective has been incorporated.

DISCUSSION OF MAINTENANCE COSTS

The best estimate model indicates that the site variable UNPAVEHAUL accounts for most of the average costs (fig. 4), but general nontimber requirements are notably important. When the average UNPAVEHAUL effect (13.4 miles × 0.206 = \$2.76) is added to the constant, +0.63, the apparent remaining effect of special maintenance requirements (presumably mostly for nontimber purposes) and of the nontimber considerations, cultural and visual concerns, is about \$2.09/M bd ft (average maintenance, \$5.48 −\$2.76 − \$0.63 = \$2.09). Although the direct link between these nontimber considerations and maintenance allowance was not always defined, they consistently contribute to this cost.

Temporary Road Cost Model

Temporary roads were a relatively small cost item and are estimated separately from specified (required) roads. Temporary roads are considered a logging cost, not required or reimbursable. The average allowance was \$1.03/M bd ft, ranging from 0 (no temporary roads needed) up to \$15.02/M bd ft. The variables associated with temporary road costs are shown in table 5. For the most part they reflect the type of yarding system.

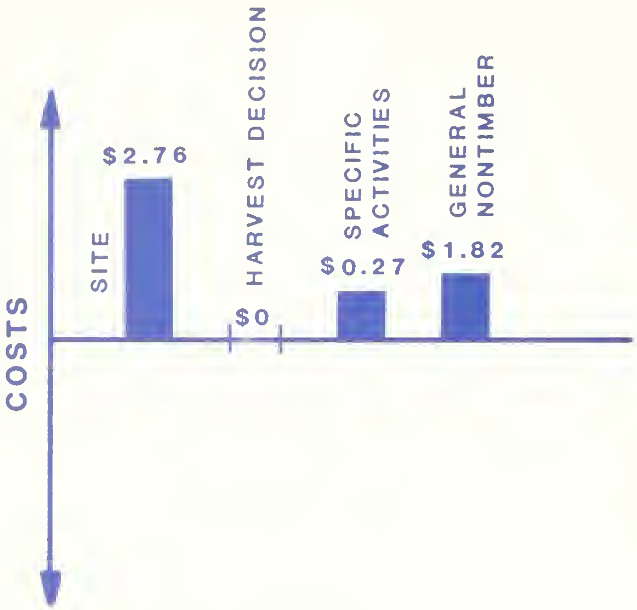


Figure 4.—Average contribution to road maintenance costs by groups of variables, $/M bd ft.

SITE VARIABLES

Road construction (CONST) and road reconstruction (RECON).—We hypothesized that permanent road construction and reconstruction might be related to temporary roads, but these variables were not significant in the best estimate model. When forced in the minimize model the variables were statistically insignificant and, as shown in table 5, they have virtually no effect on costs.

HARVEST DECISION VARIABLE

Mean acres in cutting units (MEANAC).—When mean size of the harvest unit increased by 1 acre, temporary road costs are estimated to increase by about 0.5 cent/M bd ft (b = 0.005). This is because larger units generally require more temporary roads for access, but the effect on costs is almost negligible.

SPECIFIC ACTIVITIES VARIABLES

Road spacing (SPACE).—When road spacing is restricted, costs for temporary roads increase by about $1.12/M bd ft (b = 1.124). This probably means that restrictions may preclude locating these temporary roads where construction is cheapest.

Skid slope grade (SKIDSLO).—As the slope (in percent grade) allowed for tractor logging increases, apparently fewer temporary roads are required; costs decreased by an estimated $0.03/M bd ft for each 1 percent slope (b = −0.033).

DISCUSSION OF TEMPORARY ROAD COSTS

Unlike other phases of logging, the net effect of the nontimber resource considerations on temporary roads appears to be to reduce costs. The constant (which represents an estimate of costs when all variables are at 0) is about $1.78/M bd ft and the mean cost of temporary roads is $1.10. Road spacing restrictions and size of cutting units at their mean values tend to slightly increase costs, but this is more than offset by the lower cost associated with skid slope. The relative importance of variables in explaining costs is shown in figure 5. In a statistical sense, the model was significant, but in a practical sense the cost of temporary roads was a small part of the total logging costs. Variables that should logically affect costs may have no real effect at all. There is some speculation, however, that current harvest practices use more temporary roads as a means to reduce the need for more expensive permanent roads. If this is the case, costs and variables may be different than the sales analyzed here.

Specified Road Cost Model

Roads to be constructed or reconstructed by the purchaser are often a major part of the sale cost. In the sample sales, the average was $32.52/M bd ft, and ranged from 0 (no construction required) to $112.45. The variables in the cost models are summarized in table 6.

Table 5.—Temporary road cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
CONST	mile	—		0.0002	(0.015)[2]	[3]	
RECON	mile	—		−.0002	(.017)[2]	[3]	
Specific activity							
MEANAC	acre	0.005	(0.002)	.005	(.002)	0.005	(0.002)
SPACE	0,1	1.124	(.222)	1.126	(.222)	1.124	(.222)
SKIDSLO	% slope	−.033	(.012)	−.033	(.012)	−.033	(.012)
Constant		1.785	(.475)	1.783	(.488)	1.785	(.475)
R^2		.207		.208		.207	
s.e. of model		1.173		1.177		1.173	

[1] See text for definition of variables.
[2] Indicates this variable not significant in this model.
[3] Indicates this variable forced out of this model.

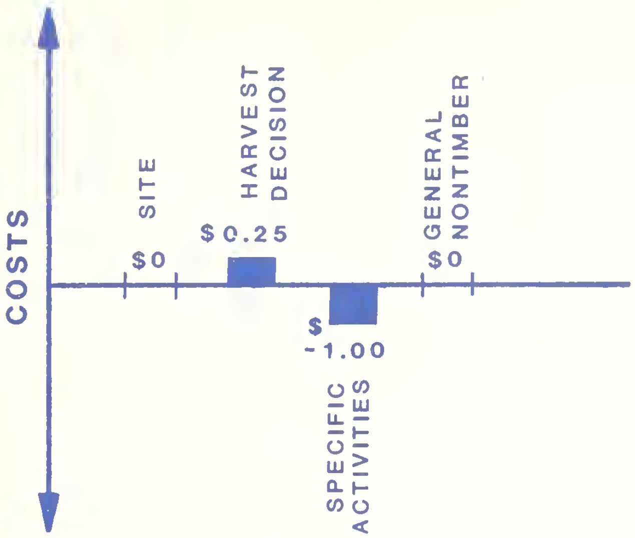


Figure 5.—Average contribution to temporary road costs by groups of variables, $/M bd ft.

SITE VARIABLES

Road construction (CONST).—As might be expected, the most important variable in this model was miles of specified road construction. Costs were predicted to increase by $2.29/M bd ft for each mile (b = 2.286) in the best estimate model.

Road reconstruction (RECON).—Road reconstruction specified in the sale was estimated to cost $0.69/M bd ft for each mile (b = 0.686) in the best estimate model.

HARVEST DECISION VARIABLES

Total acres harvested (TOTAC).—Total area in the sale was inversely related to road costs; that is, the larger a sale area, the lower the road costs per thousand board feet. As a rule, for a given amount of road construction, the more area harvested the more timber volume to bear the costs, and therefore the lower the costs per thousand board feet. In the best estimate model this was about $0.03/M bd ft lower per additional acre (b = −0.026).

Number of cutting units (NCU).—Other things being equal, the greater the dispersal of cutting units, the higher the road costs. This effect was estimated to be about $0.76/M bd ft in the maximize nontimber model (b = 0.756), but was not a significant variable in the other models.

SPECIFIC ACTIVITIES VARIABLES

Special cut and fill (CUTSEM).—If special cut and fill practices or seeding and mulching were required, costs were estimated to increase by about $8.41/M bd ft (b = 8.411) in the best estimate model, and slightly more in the minimize model. Only about 8 percent of the sales had such requirements so the average effect is small, but where these special measures are needed costs appear to be substantial. These include such measures as bin walls, terracing cuts, removing fill material, planting, and hydromulch. When the important site variables CONST and RECON are excluded, this variable has an estimated effect of about $14/M bd ft (b = 14.161).

Road spacing (SPACE).—If the minimum distance between roads was specified, costs were estimated to increase by more than $6/M bd ft (b = 6.521 in best estimate, and slightly higher in other models). The reason for this was not described, but wider spacing requirements are often in more difficult locations with less volume harvested per mile of road, which increases costs per thousand board feet.

Special road activities (ORA).—Miscellaneous other special road activities and requirements were present on about 17 percent of the sales, and, when required, were estimated to increase costs by over $6/M bd ft (b = 6.477 best estimate, and slightly higher in minimize model). This includes measures such as building sediment traps, maintaining vegetation, and time restrictions on road work. This was not, however, significant in the maximize nontimber model.

Table 6.—Specified road cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
CONST	mile	2.286	(0.275)	2.186	(0.280)	[2]	
RECON	mile	.686	(.283)	.721	(.288)	[2]	
Decision							
TOTAC	acre	−.026	(.005)	−.023	(.005)	−0.012	(0.005)
NCU	number	—		—		.756	(.175)
Specific activity							
CUTSEM	0,1	8.411	(5.166)	8.240	(5.286)	14.161	(5.610)
SPACE	0,1	6.521	(3.539)	—		6.682	(3.963)
ORA	0,1	6.477	(3.912)	7.579	(3.938)	—	
Constant		25.209	(2.877)	25.930	(2.888)	25.990	(3.382)
R^2		.340		.308		.136	
s.e. of model		18.18		18.60		20.669	

[1] See text for definition of variables.
[2] Indicates this variable forced out of this model.

DISCUSSION OF SPECIFIED ROAD COSTS

Specified roads are, on the average sale, a fairly large-cost item. The most obvious site variables—construction, reconstruction, and total area—account for a considerable portion of the average cost (fig. 6). Special activities (road spacing, cut and fill, and other road requirements) on the average add about $3.20/M bd ft.

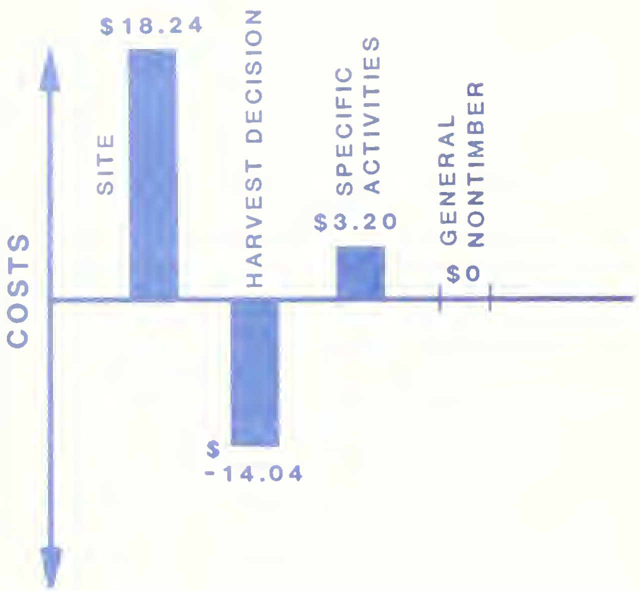


Figure 6.—Average contribution to specified road costs by groups of variables, $/M bd ft.

Slash Disposal Cost Model

Slash disposal costs ranged between $0.95 and $41.60/M bd ft, and averaged $12.40. This includes both allowance for work done by the contractor, and money collected from the purchaser for the Forest Service share of the work (usually burning). The variables associated with slash costs are presented in table 7. Most of the variables are directly related to the harvesting operation, but wildlife and soil-related considerations were also significant.

SITE VARIABLE

Volume per acre (VOL/A).—When volume increased by 1 M bd ft/acre, slash costs were estimated to be reduced by about $0.26/M bd ft (b = −0.265). Slash treatment to some extent is related to area covered, and the more volume, the less the slash disposal costs per unit of volume.

HARVEST DECISION VARIABLES

Mean acres in cutting unit (MEANAC).—The larger the size of the individual unit, the lower the slash cost, mainly because overhead costs of supervisory personnel and perimeter fireline are reduced as cutting unit size increases. The decrease was about $0.04/M bd ft (b = −0.038) for each acre increase in size.

Partial cut (PARTCUT).—Partial cutting harvest methods (shelterwood, individual tree mark, and commercial thinning) increase slash costs because both piling and burning operations require greater care to protect the residual leave trees. The best estimate model shows an increase of about $0.03/M bd ft for each 1 percent increase in the harvest area that is partial cut (b = 0.034); in the maximize model the increase is more than $0.05/M bd ft (b = 0.054).

Table 7.—Slash disposal cost model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
		b coefficient (s.e.)					
Site							
VOL/A	M bd ft	0.265	(0.065)	−0.265	(0.065)	[2]	
Decision							
MEANAC	acre	−.038	(.012)	−.038	(.012)	−0.029	(0.012)
TLOGA	% area	−.050	(.015)	−.050	(.015)	−.035	(.016)
PARTCUT	% area	.034	(.016)	.034	(.016)	.054	(.016)
Specific activity							
SPACE	0,1	3.100	(1.202)	3.100	(1.202)	3.135	(1.258)
Nontimber							
WPD&E	0,1	2.940	(1.164)	−2.940	(1.164)	−2.837	(1.217)
SOACT3	0,1	2.210	(1.215)	2.210	(1.215)	2.419	(1.271)
Constant		20.93	(2.416)	20.93	(2.416)	13.863	(1.743)
R^2		.246		.246		.175	
s.e. of model		6.30		6.30		6.59	

[1] See text for definition of variables.
[2] Indicates this variable forced out of this model.

Tractor log area (TLOGA).—Tractor skidding reduces slash costs because usually tractor piling of slash is the least costly treatment; about \$0.05/M bd ft less for each 1 percent of area tractor logged ($b = -0.050$ in best estimate, -0.035 in maximize model).

SPECIFIC ACTIVITIES VARIABLE

Road spacing (SPACE).—This restriction was estimated to increase slash costs over \$3/M bd ft ($b = 3.100$ in the best estimate, and 3.135 in the maximize). This reflects in general the greater costs of treating slash long distances from roads.

GENERAL NONTIMBER REQUIREMENTS (NTR'S)

Wildlife plan for deer and elk (WPD&E).—When deer and elk management are part of the plan, slash costs are estimated to be reduced by about \$2.94/M bd ft ($b = -2.940$). This was not explained in the data, but it may result from lighter slash loadings due to lighter cutting in areas being managed for deer and elk.

Logging modified to protect soil (SOACT3).—Soil protection activities add an estimated \$2.21/M bd ft ($b = 2.210$ best estimate, 2.419 in maximize model). This primarily reflects situations where tractors (low-cost method) cannot be used for slash treatment because of concerns for soil disturbance or compaction.

DISCUSSION OF SLASH DISPOSAL COSTS

The average costs explained by this model are shown in figure 7. The specific activities and general nontimber considerations appear to have a rather important role in explaining cost variations. It should be noted, however, that specific activities add \$0.64 and nontimber requirements reduce costs \$1.87, so that on the average their net effect is to reduce cost \$1.23/M bd ft. Considering the purpose of analyzing specific variables, however, the model appears to be highly informative; the variables have a generally consistent (across models) and logical relationship to costs.

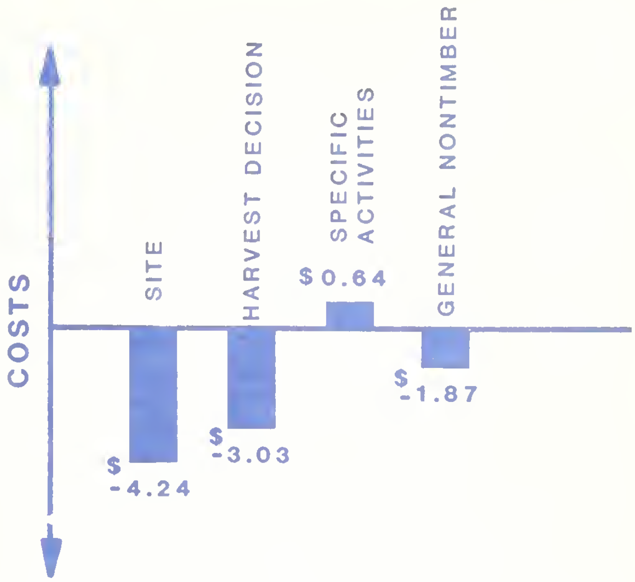


Figure 7.—Average contribution to slash costs by groups of variables, \$/M bd ft.

Discussion of Cost Models

The models discussed above indicate that a considerable number of variables were significant in explaining the cost allowance for various phases of logging. Tables 8 through 11 show the costs identified above as expressed in terms of the average sale; that is, the mean values of variables times the best estimate coefficients from tables 1—7. In table 8, the average costs of site variables—those that are essentially fixed or given for a sale—are summarized for each site variable in each logging cost item. For example, the mean value of 13.4 miles of unpaved haul road is multiplied by the UNPAVEHAUL coefficients in the hauling and maintenance models to derive a total effect of +\$9.49/M bd ft. The meaning of this can be illustrated by envisioning that a sale that had no unpaved haul miles would have no costs for this item; a 1-mile haul would be 0.502 (haul cost coefficient) + 0.206 (maintenance coefficient) × 1 mile = \$0.71/M bd ft. Note that for VOL/A the effect is negative; that is if volume per acre were very low there would theoretically be some high costs for skidding and slash because cost of tractor would be distributed over only a few thousand board feet. But as volume increases up to the sample sale average of 16 M bd ft/acre, skid costs are reduced by \$3.68/M bd ft and slash by \$4.24/M bd ft, for a total effect of −\$7.92/M bd ft.

Table 8.—Estimated average direct logging costs per thousand board feet associated with timber sale site characteristics best estimate model, 1980 dollars

		Logging phase							
Variable[1]	$\bar{X}$	Fell and buck	Skid and load	Haul	Maintenance	Temporary road	Specified road	Slash	Sum
		\$/M bd ft							
LOGM	18/M bd ft	14.02	14.36	4.10					32.48
VOL/A	16 M bd ft/acre		−3.68					−4.24	−7.92
CONST	6.3 mi						14.40		14.40
RECON	5.6 mi						3.84		3.84
PAVEHAUL	23 mi			8.76					8.76
UNPAVEHAUL	13.4 mi			6.73	2.76				9.49
Total		14.02	10.68	19.59	2.76	0	18.24	−4.24	61.05

[1] See text for definition of variables.

These effects are illustrated in figure 8. The total portion of the average logging cost explained by these site variables is $61.05/M bd ft.

Recalling that the total logging cost averaged $144/M bd ft, the site and decision variables together have explained about $38.55/M bd ft. The next question, then, and the one that is the focus of the study, is: "How much of the remaining $105.45/M bd ft ($144 − $38.55) is explained by specific activities and general considerations made for nontimber concerns?"

In table 9, the decision variables are summarized. Note that although some variables **add** to costs (skyline area and partial cut area), others **decrease** costs (tractor logging area and total sale area). The net effect of these decision variables at the mean is to decrease costs by $22.50/M bd ft. What this means is that given the conditions expressed by site variables at their mean, and then applying the six decision variables at their mean values, the effect would be $61.05 − $22.50 = $38.55/M bd ft.

In table 10, the effect of specific activity variables at the mean is summarized. These values are computed exactly the same as was explained for site variables in

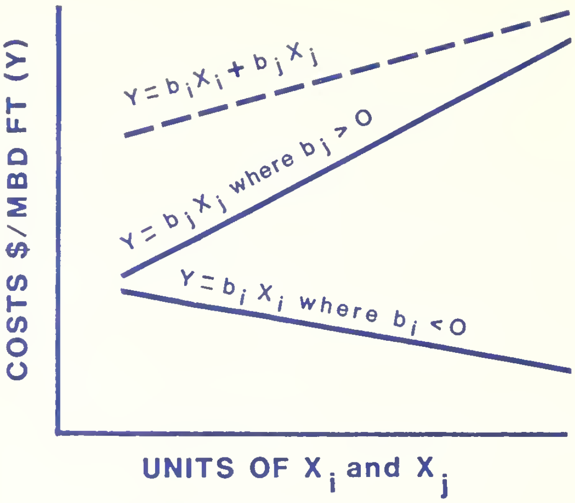


Figure 8.—Effect of continuous variables X_i and X_j on cost estimates.

Table 9.—Estimated average direct logging costs per thousand board feet associated with harvest decision variables best estimate model, 1980 dollars

Variable[1]	$\bar{X}$	Logging phase: Fell and buck	Skid and load	Haul	Maintenance	Temporary road	Specified road	Slash	Sum
		$/M bd ft							
TLOGA	62.87% of area		−9.62					−3.14	−12.76
SKYA	18.14% of area		4.10						4.10
MEANAC	50 acres/unit					0.25		−1.90	−1.65
TOTAC	540.5 acres harvested						−14.04		−14.04
PARTCUT	59% of area							2.01	2.01
GPSEL	2.4% of area	−0.16							−.16
Total		0.16	5.52	0	0	0.25	−14.04	−3.03	−22.50

[1]See text for definition of variables.

Table 10.—Estimated direct logging costs per thousand board feet associated with specific activities required for nontimber purposes, best estimate model, 1980 dollars

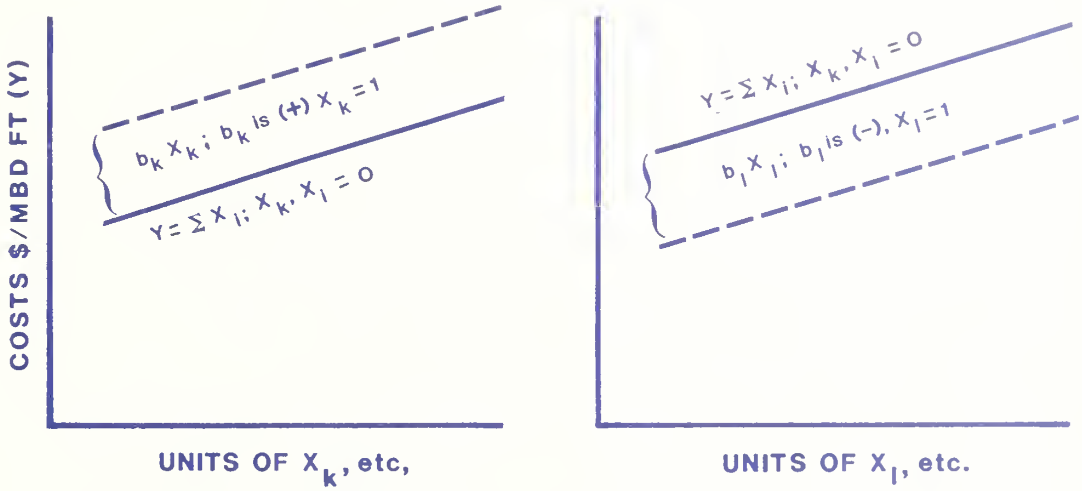
Variable[1]	$\bar{X}$	Logging phase: Fell and buck	Skid and load	Haul	Maintenance	Temporary road	Specified road	Slash	Sum
		$/M bd ft							
WHOT	0.102 of sales	−0.30							−0.30
FELLO	67.4% of area	−1.41							−1.41
ONTR	0.118 of sales	.45							.45
CORWID	0.278 of sales		1.04						1.04
RDGRADE	9.14% grade			7.36					7.36
RDWID	0.171 of sales			−.41					−.41
ORA	0.171 of sales				0.27		1.11		1.38
SKIDSLO	37.5% slope					−1.23			−1.23
SPACE	0.206 of sales					.23	1.34	0.64	2.21
CUTSEM	0.089 of sales						.75		.75
Total		−1.26	1.04	6.95	0.27	−1.00	3.20	0.64	9.84

[1]See text for definition of variables.

table 8 (b coefficient × mean value of variable). One additional feature, however, should be noted. Many of these variables are measured only as present or absent; as explained earlier, on a given sale they either have an effect equal to their coefficient if they are present, or no effect if they are absent. These effects are portrayed in figure 9. Our analysis, however, is built around a sample of 187 sales, so the sum of all the 0's and 1's divided by the 187 sales gives the mean values for these variables; it is the equivalent of the proportion of sales that have the variable present multiplied by the coefficients from tables 1–7 to give the average dollar effects shown in table 10. The total effect of all these specific activities on logging cost appraisals is +$9.84/M bd ft.

In table 11, the effects of the general nontimber requirements (NTR's) are summarized. As previously mentioned, these variables describe purpose, type, and objectives in general terms and all are 1,0 (present or absent) variables. Their average effects are computed as described above: total effect of all NTR's on logging costs is estimated to be $7.68/M bd ft. These effects on logging costs are summarized by phase and type of variable in table 12.

In table 13, the "bottom line" of each of the tables is summarized, and the values computed from the minimize and maximize models are included for comparison. The portion of the $144/M bd ft logging cost explained by the models varies from $27 to $57. Of note is that the variables we are primarily interested in—general nontimber and specific activities—are very similar in all models, totaling from about $16 to $18/M bd ft.


COSTS $/MBD FT (Y)
$b_k X_k$; b_k is (+) $X_k = 1$
$Y = \Sigma X_i$; $X_k, X_l = 0$
UNITS OF X_k, etc,
$Y = \Sigma X_i$; $X_k, X_l = 0$
$b_l X_l$; b_l is (–), $X_l = 1$
UNITS OF X_l, etc.

A. POSITIVE B COEFFICIENT **B. NEGATIVE B COEFFICIENT**

Figure 9.—Effect of present/absent (1,0) variables on cost estimates.

Table 11.—Estimated direct logging costs/M bd ft associated with general nontimber requirements (NTR's) best estimate model, 1980 dollars

Variable[1]	$\bar{X}$	Logging phase							
		Fell and buck	Skid and load	Haul	Maintenance	Temporary road	Specified road	Slash	Sum
		$/M bd ft							
SOPLAN	0.866 of sales		4.13						4.13
SOACT3	0.187 of sales	0.43	.65					0.41	1.49
WPD&E	0.775 of sales			1.31				–2.28	–.97
WLFOOD	0.337 of sales			.51					.51
WLOTH	0.214 of sales		.70						.70
CULPLAN	0.695 of sales				1.27				1.27
VQO	0.428 of sales				.55				.55
Total		0.43	5.48	1.82	1.82	0	0	–1.87	7.68

[1] See text for definition of variables.

Table 12.—Effect on average logging costs, by phase and type of variable, 1980 dollars

Phase	Site	Decision	Specific activity	Nontimber requirements
	$/M bd ft[1]			
Felling and bucking	14.02	-0.16	-1.26	0.43
Skidding and loading	10.68	-5.52	1.04	5.48
Haul	19.59	0	6.95	1.82
Road maintenance	2.76	0	.27	1.82
Temporary roads	0	.25	1.00	0
Specified roads	18.24	14.04	3.20	0
Slash	-4.24	-3.03	.64	1.87
Total, logging	61.05	-22.50	9.84	7.68

[1] Derived by multiplying b coefficients, tables 1–7, by $\overline{X}$ for each variable.

Table 13.—Estimated average direct logging costs associated with various sale characteristics, 1980 dollars

Characteristic	Best estimate	Minimize nontimber	Maximize nontimber
	$/M bd ft		
Site characteristics	61.05	60.45	0
Harvest decision variables	22.50	-19.55	9.94
Specific activities	9.84	7.63	10.78
General nontimber requirements	7.68	8.40	6.44
Total	56.07	57.03	27.16

Given that the estimated costs of nontimber-related considerations in planning and conducting sales are moderately small, the question remains just how much error is involved in these estimates. As indicated by the standard errors in tables 1–7, there is considerable variation in the b coefficients; for most variables, this error around the estimated mean coefficient is greater than the difference between coefficients in the three analyses. From a practical standpoint, this means the normal variation in costs estimated by the best estimate model is of more importance than alternate estimates by the minimize or maximize models. For example, in the best estimate model, the specific activities and general nontimber requirements total $17.52/M bd ft; in the minimize model they are slightly less, $16.13.

Bid Difference Model

Up to this point, the analysis of the effect of nontimber concerns has been from the viewpoint of the seller, the Forest Service. When the logging costs have been totaled and allowance made for manufacturing and other related costs, total costs are subtracted from the estimated value of the manufactured product to derive the indicated stumpage value. This is an estimate of what a purchaser of average efficiency would be willing to pay for the stumpage. Whatever the purchaser bids in excess of stumpage value is called the bid difference. In the sample sales the bid difference averaged $67/M bd ft.

The objective of this part of the analysis is to answer the question: "Do the nontimber requirements on a timber sale affect the purchaser's bid?" If the purchaser feels that some part of the logging appraisal has not allowed enough to cover his costs, he may reduce his bid. Conversely, if he feels he can meet requirements for less than the estimated cost, he may increase his bid.

The analysis of bid difference is summarized in table 14. Again, the three alternative models—best estimate, minimize nontimber, and maximize nontimber—were used to try to establish a range of estimates for the variables.

The individual variables are discussed in detail below. Conceptually, the effect of these variables on bid difference is additive to their effect on cost allowance; that is, if a bidder feels the appraisal either overallows or underallows for costs of some logging condition or requirement, he could conceivably increase or decrease his bid margin accordingly. Again, the discussion relates to the best estimate model but notes if there are any major differences in the other models.

SITE VARIABLES

Logs per M bd ft (LOGM).—Bid margin was increased $1.66/M bd ft (b = 1.665) for each additional log per thousand board feet in the best estimate model (b = 1.809 in minimize). In general, more LOGM would be expected to increase costs, but as noted, the bid difference may not reflect net costs, per se, but rather the bidder's judgment of logging cost estimate. Results suggest that purchasers felt they could do better than logging costs related to LOGM.

Volume/acre (VOL/A).—Volume per acre was not significant in the best estimate model, but when forced into

Table 14.—Bid difference model

Variable[1]	Unit	Best estimate		Minimize nontimber		Maximize nontimber	
				b coefficient (s.e.)			
Site							
LOGM	number	1.665	(0.474)	1.809	(0.496)	[2]	
VOL/A	M bd ft	—		.619	(.468)[3]	[2]	
CONST	mile	—		-.727	(.578)[3]	[2]	
RECON	mile	1.113	(.621)	1.357	(.630)	[2]	
PAVEHAUL	mile	.812	(.186)	.716	(.204)	[2]	
UNPAVEHAUL	mile	—		-.370	(.366)[3]	[2]	
Decision							
SKYA	% area	—		—		0.429	(0.141)
MEANAC	acre	-.190	(.186)	-.180	(.080)	-.170	(.082)
Specific activity							
RDWID	0,1	-29.089	(8.969)	-28.330	(8.930)	-30.360	(9.480)
SPACE	0,1	-16.663	(8.347)	-15.973	(8.255)	-18.848	(8.848)
Constant		28.653	(11.648)	25.437	(17.140)	91.712	6.278)
R^2		.258		.273		.154	
s.e. of model		43.60		43.23		46.27	

[1] See text for definition of variables

[2] These variables forced out of this model.

[3] These variables not significant at $\alpha = 0.05$.

the minimize model, bid difference increased about \$0.62/M bd ft (b = 0.619) for each additional thousand board feet per acre. This suggests that even when volume per acre increased and the costs allowed for logging decreased (from earlier models) bidders still increased their bid margin.

Construction (CONST).—Road construction also was not significant in the best estimate model, and was also not statistically significant when forced into the minimize model. The indicated effect was to reduce bid difference by \$0.73/M bd ft (b = −0.727) per mile of construction. This suggests road construction has a negative effect, but we can only speculate that it may be related to cost allowance made for roads or some other reason.

Reconstruction (RECON).—Miles of road reconstruction was significant in both best estimate and minimize models, with positive coefficients of b = 1.113 and 1.357, respectively. This suggests that purchasers increased their bid by \$1.11 to \$1.36/M bd ft for each mile of reconstruction. Two plausible reasons are that the appraised allowance was greater than the purchaser's actual costs; or that reconstruction is involved in areas already developed for timber and these have more favorable logging conditions—less remote, better timber, and so on—than previously unroaded areas.

Paved haul (PAVEHAUL).—Paved haul miles was significant in both the best estimate and minimize models, and indicated bid difference increased by about \$0.72/M bd ft (b = 0.716, minimize) to \$0.81 (b = 0.812, best estimate) per thousand board feet per mile. Again, apparently the purchasers saw a cost advantage over and above the cost allowance made for hauling on paved roads.

Unpaved haul (UNPAVEHAUL).—Unpaved hauling distance was not significant in the best estimate model and was not statistically significant when forced into the minimize model. The indicated bid decrease, however, was \$0.37/M bd ft (b = −0.370). This suggests that the purchaser thought total cost of unpaved haul miles was greater than that allowed for in the appraisal.

HARVEST DECISION VARIABLES

Skyline area (SKYA).—This variable was significant only in the maximize nontimber model, and indicated bid difference was decreased by about \$0.43/M bd ft (b = −0.429) for each 1 percent increase in SKYA. This is consistent with the general idea that skyline yarding is considered costly and more unpredictable than other methods of yarding and purchasers accordingly reduce their bids.

Mean acres in cutting unit (MEANAC).—This variable was significant in all three models and indicated bid margin is reduced by \$0.19/M bd ft for each additional acre (b = −0.190 in best estimate). This reverses the notion that increased size of a cutting unit brings some economies of scale to logging. There are, however, some reasons why larger units reduce bids. First, because clearcutting (usually the least costly method) is restricted to smaller units, large units indicate some type of partial cutting. Second, if road density is restricted, yarding distance is longer on large units. Finally, sales often have restrictions that require the completion of one unit before beginning another, and on large units the purchaser may feel this restricts his flexibility.

SPECIFIC ACTIVITIES VARIABLES

Road spacing (SPACE).—This variable, significant in all three models, indicated that when road spacing on the sale was restricted, bid difference was reduced by \$15.97 to \$18.85/M bd ft. This is generally consistent with the idea that wider road spacing increases yarding costs.

Road width (RDWID).—This variable was significant in all three models and indicated that when special road widths were specified, bid difference decreased by $28.33 to $30.36/M bd ft. This result suggests that abnormally wide or narrow roads are unusually costly to construct and that costs allowed for such roads are less than the purchaser's estimates.

COMMENTS ON BID DIFFERENCE MODEL

The bid difference model attempts to explain variations in bid difference—bid minus indicated stumpage value—in terms of variables that were significant in explaining logging cost appraisal allowances. Factors such as market expectations and competitiveness among stumpage buyers may also affect bidding. Even if consideration is limited to logging operations, bid differences may reflect advantages or disadvantages unique to a given buyer bidding on a sale. Jackson (1983) discusses how logging, manufacturing, and other considerations may affect stumpage appraisals and bidding. These considerations were not included in the bid models (many of them could not even be quantified). The bid difference models, however, appear to provide at least a general picture of how harvesting conditions and requirements may affect bid margins (fig. 10). Even without some of the important factors of bidding behavior, the analysis appears to yield plausible and stable estimates of the effects of nontimber considerations. Most coefficients did not differ appreciably among the three models.

When the dollar effect of these variables is computed (mean value of variable × b coefficient), the portion of bid difference "explained" by the best estimate model is:

LOGM	29.97
RECON	6.23
PAVEHAUL	18.67
Total, site variables	54.87
MEANAC	−9.48
Total, harvest decision	−9.48
RDWID	−4.97
SPACE	−3.43
Total, specific activities	−8.40

Because a positive bid difference is, in effect, a return to the seller (more received than what the timber was appraised to be worth), this model says that the site characteristics have benefited the seller. Conversely, because the specific activity variables RDWID and SPACE have decreased the bid margin, their effect is a cost to the seller. Therefore, the "cost" effects of these variables in the bid difference can be added to the costs of nontimber considerations determined in the logging cost models to derive the estimated total effect on stumpage values.

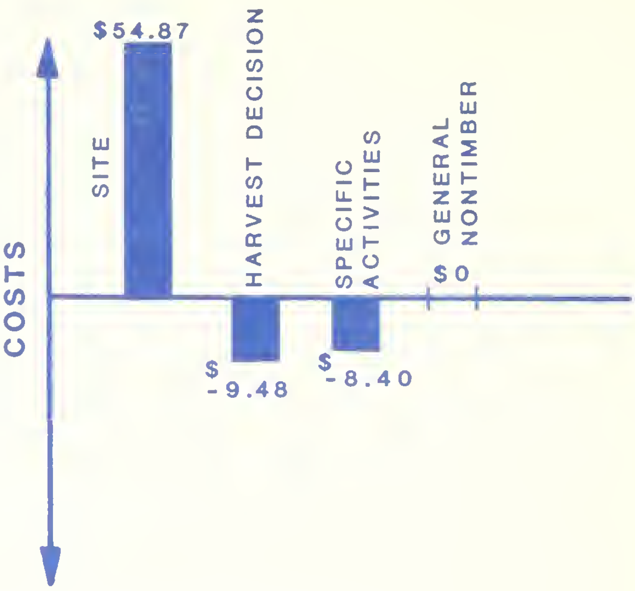


Figure 10.—Average contribution to bid difference by groups of variables, $/M bd ft

Total Effect of Nontimber Considerations on Stumpage Values

The analyses of logging costs and bid difference in the preceding sections have developed estimates of how various nontimber considerations affect appraised costs and bid difference, and using the mean values of the nontimber variables, have developed estimates of average costs. Table 15 shows the total effect of these costs; namely, combined effect on stumpage values. For example, for the best estimate models the specific activity variables

Table 15.—Total effect of general nontimber requirements and specific activities costs for logging phases and bid difference

Phase	Best estimate	Minimum	Maximum
		$/M bd ft	
Felling and bucking	−0.83	−0.83	0.51
Skidding and loading	6.52	6.33	5.84
Haul	8.77	8.77	8.80
Road maintenance	2.09	2.06	1.53
Temporary roads	−1.00	−1.00	−1.00
Specified roads	3.20	2.03	2.64
Slash	−1.23	−1.23	−1.10
Subtotal, logging	17.52	16.13	17.22
Bid difference	8.40	8.13	9.07
Total	25.92	24.26	26.29

and general nontimber requirements were estimated to "cost" $17.52/M bd ft. When the effect of specific activities from the bid difference analysis, $8.40/M bd ft, is added (because the reduction in bid is the same as an increase in costs), the resulting total is $25.92/M bd ft. Forest Service stumpage receipts were reduced by this amount to meet nontimber considerations on the 187 sales studied. Estimated totals for the minimize and maximize models are also shown in table 15. The range of these estimates, $24.26 to $26.29/M bd ft, indicates little difference in the "bottom line," even though quite different assumptions underlie the estimates. The 95 percent confidence interval around these means is discussed in appendix A.

SUMMARY AND DISCUSSION

Timber sales conducted on seven National Forests in northern Idaho and western Montana during 1975-80 (N = 187 sales) were analyzed to determine (1) if provisions to protect or enhance nontimber resources affected appraisal allowance for logging costs, and (2) if these provisions affected the amount purchasers bid for the timber.

For purposes of analyses, appraisal costs were divided into seven items (logging phases) and a regression analysis made for each. In these regression analyses, three approaches (models) were used to establish a range of estimated nontimber costs. The best estimate model used the conventional stepwise regression approach of adding explanatory variables to the model in order of their significance. Variables included characteristics of the timber sale site, harvest methods, and both general and specific nontimber requirements. An alternative analysis estimated how small the effect of nontimber considerations would be if the effects of selected site variables were arbitrarily included (this minimized nontimber costs). A third analysis maximized the effect of nontimber considerations by arbitrarily excluding site variables: this gave an estimate of how large nontimber costs might be.

The principal findings on how appraisal costs were related to nontimber considerations were:

- Most of the explanation of appraised costs is associated with site variables such as volume per acre and haul distance, or with decisions such as harvesting method and logging technique. Several variables reflecting general nontimber considerations and specific activities were statistically significant in each of the seven logging cost models.
- The net effect of nontimber concerns on the average sale (at the mean value of all variables) was to increase total appraised logging costs (sum of seven items analyzed) by about $17.52/M bd ft (best estimate).
- Of eight nontimber resources considered in the analysis, soil and wildlife appeared to have the biggest effect on costs. Cultural concerns and visual quality considerations were also statistically significant in some cost items but had less dollar effect. Among various specific activities undertaken for nontimber concerns, road-related activities were the most significant, and logging-related activities, especially felling and yarding, were the next most important.

The appraisal cost analyses estimate how much the Forest Service allows for nontimber concerns when setting stumpage value. An additional cost is the effect of nontimber considerations on the purchaser's bid difference; that is, the margin of his bid over the seller's (Forest Service) estimated value of the stumpage. This bid difference was also analyzed using the three types of models to estimate the range of effects. In this analysis, several nontimber considerations were statistically significant, and their net effect on bid difference was to reduce the bid margin by about $8.40/M bd ft (best estimate model).

When these two components are combined, the net effect of nontimber concerns is about $26/M bd ft:

Cost effect on logging cost appraisal items	
Specific activities for nontimber purposes	$9.84
General nontimber objectives	7.68
Cost effect on bid difference, specific activities	8.40
	$25.92/M bd ft

It should be emphasized, however, that this is an average for 187 sample sales; on any one sale the effects would probably vary considerably. This $26/M bd ft represents about 18 percent of the $144/M bd ft average logging costs of the sample sales, and about 7 percent of the final product value of $340/M bd ft (log scale). Because purchasers bid an average of $107/M bd ft on the sample sales, the estimated nontimber costs were equal to about a quarter of the bid price.

The estimated effects of nontimber considerations on appraisal allowance and bid difference, as summarized in the above tables and discussion, are probably a reasonable approximation of average conditions for the sample sales during the time period covered. It should be recognized, however, that current and future sales may have characteristics and requirements different from those included in this study and may reflect experience gained in meeting nontimber goals over the past decade. It should also be recalled from the introduction that the costs analyzed here do not include costs of Forest Service administration and do not reflect opportunity costs of alternative management practices for the forest land.

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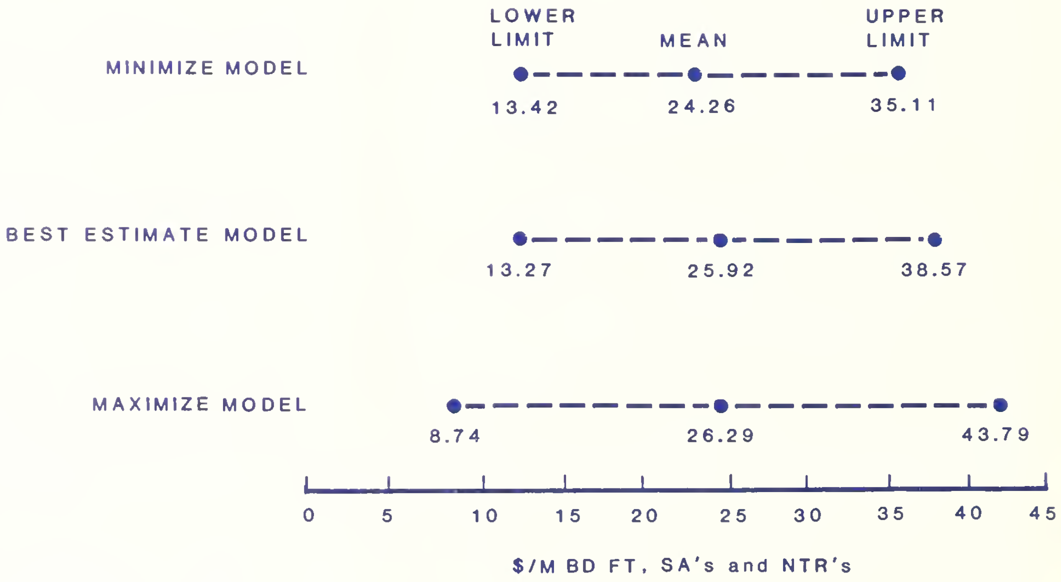
APPENDIX A: CONFIDENCE INTERVAL FOR ESTIMATED COSTS OF SPECIFIC ACTIVITIES AND NONTIMBER REQUIREMENTS

In the text, three modeling approaches (philosophies) were used to derive a range of estimates of the costs of specific activities (SA's) and nontimber requirements (NTR's). A standard approach of showing variation (range) around an estimate is to use confidence intervals. The general confidence interval used is the following:

$$\hat{Y} \pm t_{\alpha,n} \times \text{standard error}$$

By selecting an alpha value (α), the confidence level of the interval is set. In the following graph the 95 percent confidence interval ($\alpha = 0.05$) around the predicted costs of combined specific activities and nontimber requirements is presented for each of the three modeling approaches.



APPENDIX B: SUMMARY STATISTICS FOR SAMPLE TIMBER SALES

Table 16.—Timber sale characteristics, 187 sample sales, northern Idaho and western Montana

Description of variable	Name	Unit	Mean	SD	Min.	Max.
Total volume	TOTVOL	MM bd ft	8.209	5.479	1.18	27.930
Volume per acre	VOL/A	M bd ft	16.0	8.0	2.2	51.7
Total acres harvested	TOTAC	acre	540.5	348.82	74	1,597
Logs per M bd ft	LOGM	number	17.99	7.44	5.10	47.90
Paved haul distance	PAVEHAUL	mile	23.03	18.24	0	84.80
Unpaved haul distance	UNPAVEHAUL	mile	13.37	10.25	0.10	44.00
Mean acres in cutting units	MEANAC	acre	49.86	42.82	6	258
Number of cutting units	NCU	number	15.3	10.3	1	50
Road construction	CONST	mile	6.3	5.9	0	30.8
Road reconstruction	RECON	mile	5.6	5.6	0	23.9

Table 17.—Timber sale cutting methods, percent of sale area, 187 sample sales, northern Idaho and western Montana

Description of variable	Name	Unit	Mean	SD	Min.	Max.
Clearcut	CC	percent	38.28	32.40	0	100
Group selection	GPSEL	percent	2.44	12.61	0	94
Partial cut	PARTCUT	percent	58.97	33.41	0	99

Table 18.—Timber sale yarding method, 187 sample sales, northern Idaho and western Montana

Description of variable	Name	Unit	Mean	SD	Min.	Max.
Tractor log area	TLOGA	percent	62.87	32.21	0	99
Skyline area	SKYA	percent	18.14	26.60	0	99
Jammer log area	JLOGA	percent	17.72	25.98	0	94

Table 19.—Timber sale logging specific activities and requirements undertaken or modified for nontimber resources

A. CONTINUOUS VARIABLES

Description of variable	Name	Unit	Mean	SD	Min.	Max.
Directional felling	FELLO	percent of area	67.38	44.74	0	99
Road grade	RDGRADE	percent grade	9.14	2.27	4	15
Skid slope grade	SKIDSLO	percent slope	37.43	7.67	0	65
Closure barriers	CLOSBAR	number	1.54	4.05	0	30

B. PRESENT OR ABSENT (1,0)

Requirements	Name	Proportion of sales
Road width other than normal	RDWID	0.171
Special cut and fill	CUTSEM	.089
Special road activities	ORA	.171
Road spacing restricted	SPACE	.206
Corridor width constrained	CORWID	.278
Whole-tree logging	WHOT	.102
Snow removal required	SNOW	.182
Other nontimber requirements	ONTR	.118

Table 20.—Timber sale general nontimber resource consideration (present, absent 1.0 variables)

Description of variable	Name	Proportion of sales present
Soil plan (map, etc.)	SOPLAN	0.866
Logging modified to protect soil	SOACT3	.187
Visual quality objective in plan	VQO	.428
Cultural features or activities in plan	CULPLAN	.695
Wildlife plan for deer and elk	WPD&E	.775
Wildlife food protected or enhanced	WLFOOD	.337
Wildlife travel zone protected	WLTRAVEL	.059
Miscellaneous other wildlife considerations	WLOTH	.214

Benson, Robert E.; Niccolucci, Michael J. Costs of managing nontimber resources when harvesting timber in the Northern Rockies. Research Paper INT-351. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 22 p.

Some 187 Forest Service timber sales in western Montana and northern Idaho were analyzed to determine the costs of protecting or enhancing nontimber resources during timber harvesting. Linear regression models were used to estimate how various activities undertaken to meet nontimber concerns affected costs for various phases of logging, and also the bids for stumpage. Costs of managing nontimber resources averaged $26 per thousand board feet of stumpage sold.

KEYWORDS: costs, harvesting, nontimber resources, logging costs, timber appraisals, bidding

United States
Department of
Agriculture

Forest Service

Intermountain
Research Station
Ogden, UT 84401

Research Paper
INT-352

November 1985

Combustion Recovery: A Measurement of Fire Retardant Extinguishment Capability

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CLEMSON UNIVERS
FEB 25 1986
PUBLIC DOCUMENTS

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RESEARCH SUMMARY

This study describes a laboratory method (and results) for quantifying the fire-extinguishing capabilities of different water/chemical combinations commonly used to suppress fires. Pine needle fuel beds were ignited and allowed to reach maximum steady-state energy release. They were then sprayed with fire retardants to decrease the energy release rates to different levels above zero. After measured applications were made, the steady-state energy release rate and its duration after the combustion had recovered were recorded by monitoring the weight loss of the treated fuels as they burned. Energy release rates and duration were compared for fires sprayed with water, water mixed with different amounts of fire retardant chemicals, and water mixed with different amounts of guar gum thickener.

Combustion recovery data from these demonstration fires indicate that plain water is the principal agent to initially decrease both flaming and smoldering combustion. Adding retardant chemicals did not improve flame "knockdown" capabilities of water, but the chemical additives minimized subsequent rate and duration of energy release. The test method was sensitive enough to show that solutions of monoammonium phosphate are more effective in slowing combustion recovery than plain water, and that a slightly thickened solution slowed recovery more than either an unthickened solution or one thickened to 900 cP.

Combustion Recovery: A Measurement of Fire Retardant Extinguishment Capability

Aylmer D. Blakely

INTRODUCTION

Water or water with chemicals added (retardants) is commonly used to combat wildland fires by two general application methods—applying liquid directly to flaming combustion (direct attack) or to unburned fuels that are in the path of the fire (indirect attack). The direct method is usually intended to control fire by totally extinguishing all combustion. Assuming correct placement of retardant, total extinguishment (stopping both smoldering and flaming combustion) success is usually dependent on the fire intensity, fuel loading and arrangement, and total volume of liquid and its application rate. Direct attack is meant to absorb the propagating heat flux and decrease the oxygen supply sufficiently to stop all combustion. Indirect attack is also intended to absorb heat energy, plus chemically alter the pyrolysis of rapidly heating fuels enough to change the composition and flammability of evolved products. Combinations of these two general methods are used, depending on the fire/fuel situation. Even though the indirect method may be more efficient in many instances (no evaporation above the flames), the direct method is very frequently used on wildland fires with both aerial and ground application.

Numerous methods have been used under controlled conditions to determine the effectiveness of water and retardants for extinguishing combustion. One principal method has been to spray water or retardants onto flaming fuels of different types and arrangements. Different retardants may have similar capabilities for reducing flaming combustion but be very different in their ability to maintain that reduced state. The water in the retardant appears to be the principal agent to reduce the flaming by absorbing heat energy, diluting flammable gases, and smothering to reduce oxygen availability. The retardant chemicals act to change the flammability and quantity of evolving gases (Philpot 1971) and to change the droplet sizes and flow characteristics of the water (Andersen and Wong 1978). Measuring specific effects on fire behavior is difficult and has been done with very general parameters such as total energy release (USDA 1955), flame height (Johanson 1967), flame temperatures (Hardy and others 1962), emitted radiant energy (Phillips and Miller 1959; Dibble and others 1961; USDA 1955), times until flaming or glowing stopped (Truax 1939; Grove and others 1962), and total amount of liquid required to reach a predetermined combustion state and application rates needed to produce that state (Truax 1939; Tyner 1941; George and Blakely 1972).

This study compares energy release rates (E_R) of burning fuel beds sprayed with various water or chemical treatments. When liquid is insufficient to stop all combustion, flaming recurs (combustion recovery) because fuels beneath the level of treatment penetration continue to smolder. The heat of smoldering combustion dries and reignites fuels and sustains combustion—unless additional liquid is applied. In this study, increased amounts of liquid are applied to successive identical fires and the results are monitored until so large a volume is applied that all combustion ceases soon after application is stopped.

Although two of the same parameters (energy release rate and total application) used in other studies are being measured, in this study they are used to examine the consequences when the combustion is not totally extinguished and what differences on long term effects (time to recovery and E_R) there are between application rates, total application, retardant salt concentrations, and viscosities. This study method was designed to determine the importance of water in decreasing flaming combustion, with and without fire-retarding chemicals, and also to what extent the chemicals remaining after evaporation prevent or retard combustion recovery and subsequent fire propagation and spread.

EXPERIMENTAL METHOD FOR QUANTIFYING COMBUSTION RECOVERY

Individual fires were sprayed with small amounts of water or water that contained chemicals, and magnitude and duration of E_R were recorded. If too much chemical or water was used, the fire would be extinguished and the amount of excess liquid not known. In pine needle fuel beds it is very difficult (if not impossible) to visually determine when the fire is totally out and therefore when to stop applying water. In past extinguishment tests, the fire was sprayed until the flames were visually out, then again until all smoldering (smoking) was stopped (Truax 1939; Grove 1962). The tests quantified how much water/chemical is required to provide different stages of extinguishment (flames out and smoldering out). They did not take into account situations when insufficient water/chemical was applied.

Because extinguishment is difficult to determine visually, the method used in this study conducts several trials by adding small amounts of water or retardant salt or more thickening agent to successive fires until combustion does not recover (determined by monitoring weight loss). This method reveals a definite point when combustion stops.

Plain water or water that contains fire-retarding chemicals, with and without thickening agents, was applied to burning pine needle fuel beds from a trolley-mounted spray nozzle (fig. 1) above the fuel beds. The nozzle size, pressure, and trolley speed controlled the amount of retardant applied to each burning fuel bed. Effect on combustion was determined by continuously monitoring the weight loss of the burning fuel. Weight loss can be related directly to E_R by associating the fuel weight loss rate with the measured heat content for the specific fuel (Rothermel and Anderson 1966; George and Blakely 1970).

Fuel beds were 4 ft long, 3 ft wide, and 3 inches deep, using 4 lb of ponderosa pine needles. The fuel loading was 0.33 lb/ft^2 and the bulk density was 1.33 lb/ft^3. Needles were dried to equilibrium at room temperature and fuel moisture content was from 6 to 7.5 percent by weight. Fuels were burned in a wind tunnel under controlled conditions of 5 mi/h (±0.5), 90 °F (±2°), and 20 percent (±2 percent) R.H. (These environmental conditions can be related to wildfire situations by the following: When needles are classed as fuel type U, the National Fire-Danger Rating System (NFDRS) grades fires in untreated fuels as spread component 5, energy release component 38, and burning index 34.) Calculated using 8,745 Btu/lb, the entire fuel bed contained a potential of approximately 34,982 Btu. The average maximum untreated burning rate for five untreated fires averaged 296 Btu/s, with flame lengths reaching 3 to 4 ft. Ninety-five percent of the total energy potential (33,233 Btu) was expended within 4 minutes.

The fuel bed was ignited in a manner that insured rapid ignition of the entire surface. A 15-ft cord that had been soaked in xylene was laid along each side, down the middle of the bed, and across the upwind end. The upwind center of the cord was ignited by an electric hot wire and the fire spread along the cord to ignite the fuel bed edges and center within 10 seconds. Within 20 seconds of ignition, the entire surface of the bed was flaming. The fire was allowed to burn downward into the bed until the maximum E_R was detected and had begun to level off. The maximum E_R occurred approximately 45 seconds after ignition. At that time the extinguishant was applied to the flaming fuel bed. Approximately 27 percent of the total fuel weight had been consumed before the sprayer was turned on.

Energy Release Measurement

To measure total E_R, the fuel bed was placed on a top-loading digital balance that was connected through a digital/analog converter to a microcomputer (fig. 1). The computer was programmed to record weight changes during sprayer calibration and while the fuel was burning and being extinguished. The computer displayed four parameter traces versus time: total weight, radiation, sprayer tank pressure, and manually activated event

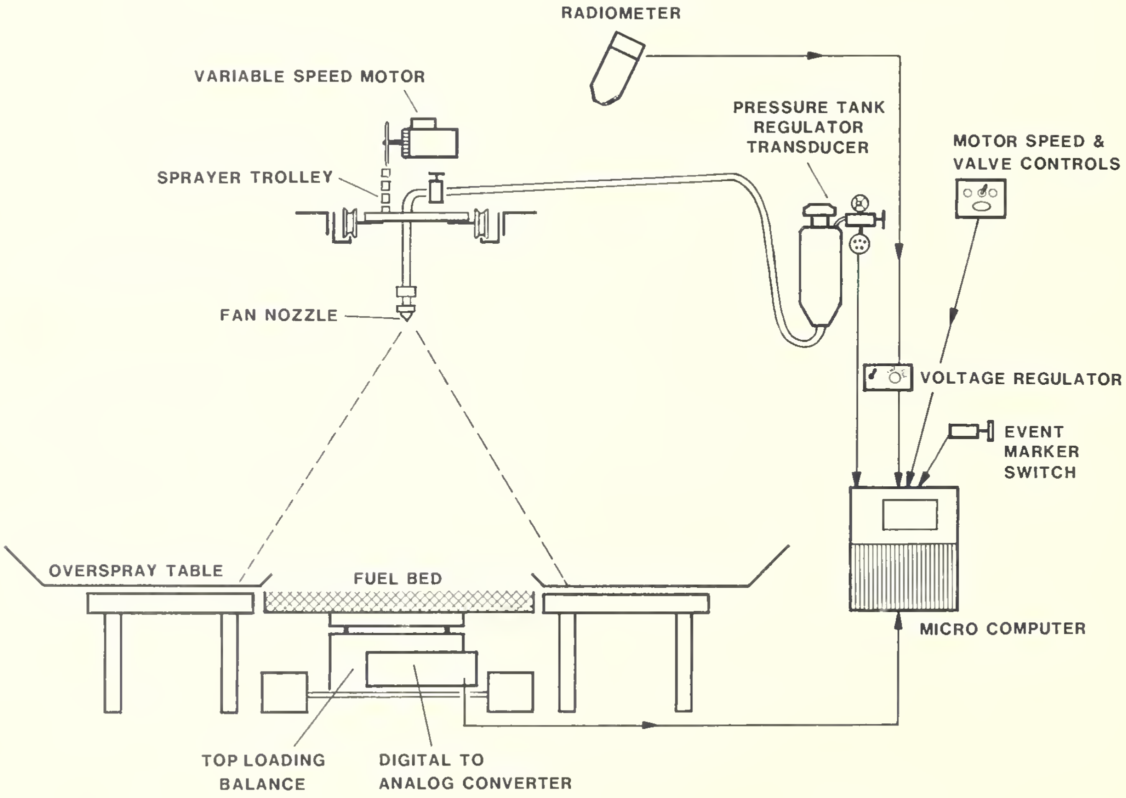

Figure 1.—Overhead sprayer and fuel bed weighing system.

marks. All data were recorded on tape for later transfer to a computer disk.

To quickly determine E_R (difficult with the weight loss trace), a Gier-Dunkle directional radiometer was mounted above the fuel bed and to one side (fig. 1). The irradiance data were transmitted directly to the microcomputer and recorded as millivolts. When the irradiance trace reached a maximum rate, the water/chemical application was started. The radiometer was attached to the top of the tunnel 8.4 ft above the top surface of the fuel bed. It was 3.2 ft to the side of the bed and was tilted 67° downward to have maximum viewing of the width of the fuel bed. The placement of the radiometer in this position allowed it to receive irradiance from the entire fuel bed surface and up to 4-ft flame heights.

Liquid Application

Water or water that contained monoammonium phosphate (MAP) with and without guar gum thickener was directed to the flaming fuel with an overhead nozzle that delivered a flat, fan-shaped pattern. A 2-gal pressurized tank was mounted outside the wind tunnel with a flexible tube that ran up the tunnel wall and across the top to a movable trolley. The tubing was connected to a pipe that extended down from the trolley and placed the nozzle tip 6.23 ft above the fuel bed surface. An electric solenoid activated a valve just ahead of the nozzle for instantaneous on and off flow. The valve design was straight-through flow to prevent shearing the liquid, which might change the viscosity and thus droplet sizes.

The trolley was moved over the bed by a variable-speed motor and sprocket-chain drive that were controlled from outside the wind tunnel. The sprayer was calibrated by placing a large aluminum pan, the same size as the fuel bed, on the balance and spraying liquid onto it. The balance was connected to the microcomputer that calculates the total application and rate of liquid falling onto the pan surface. Small narrow trays laid in the large tray were used to determine the uniformity of chemical coverage across the bed perpendicular to the direction of nozzle movement. The coverage was adjusted to a consistent pattern by varying pressure in the spray tank and nozzle height above the fuel. Droplet size and flow rate were varied by changing pressure and nozzle size. Total application and rate were controlled by the speed at which the trolley carried the nozzle along the full length of the fuel bed.

An example of energy release, from fuel bed ignition until all combustion stops, is shown in figure 2. Control beds with no liquid application (weight loss trace J) were ignited and allowed to burn freely until all combustion had stopped. The entire fuel bed surface was burning within 6 seconds, then E_R increased rapidly as the fire progressed downward into the fuel. The E_R increased for about 90 seconds then started to drop off slowly. By the time the highest combustion rate was reached, only about 27 percent of the fuel had been consumed. Within 4 minutes, 95 percent of the total bed weight was consumed and part of the remaining 5 percent was consumed (mainly by smoldering combustion) very slowly over the next 15 minutes. The highest combustion rate was about 300 Btu/s. After 95 percent fuel consumption, the rate was about 15 Btu/s; after 10 minutes about 7 Btu/s.

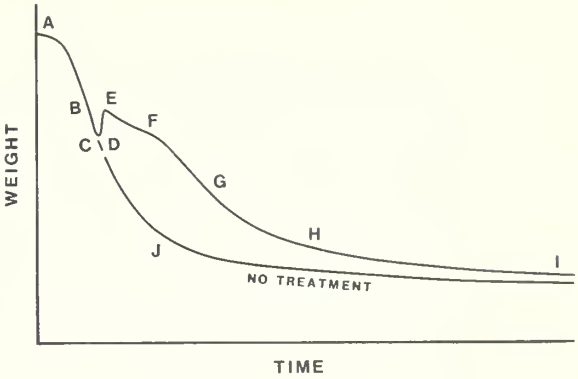

Figure 2.—Typical stages of fuel bed weight loss during retardant experiments.

When water/chemical is applied, the immediate decrease in flaming combustion depends on the total volume of water applied. Early in the study during preliminary burns, it was recognized that water was the principal factor contributing to flame extinction; therefore, comparison treatments were changed from equal weights of liquid (with and without retardant chemicals) to equal weights of water with different weights of chemical added as the variable. Designated segments (noted with capital letters) of the weight loss curve are for tests with liquid applied and are shown in figure 2. The weight loss trace shows a rapid loss for a few seconds, then E_R is at a steady-state for up to 4 minutes (depending on application), then increases again but has another steady-state period before gradually decreasing until burnout. (A steady-state period is one during which the rate of energy release remains constant.) The following is an explanation of each general segment of the weight loss curve example in figure 2.

Segment A. Slight weight loss caused by burning xylene and fuel.

Segment B. Surface of fuel bed becomes totally involved and maximum energy release rate occurs.

Segment C. During maximum E_R, chemical is applied to burning fuel bed starting at downwind end. The sprayer moves upwind covering entire fuel bed from front to rear and side to side within 2 to 10 seconds, depending on the trolley speed and the amount of liquid application.

Segment D. As more and more liquid contacts the flaming bed, the weight loss rate begins to decrease and the added liquid causes the total fuel bed weight to increase. Application rate becomes same as weight loss rate for a short period.

Segment E. The sprayer is shut off and total weight begins to show a decline again, but offset in time and at a different rate from the untreated burning rate. Flaming combustion is at a minimum. In some cases the force of the retardant hitting the bed causes the recorder trace to drop when the sprayer is shut off. (This should not be confused with a sudden E_R decrease.)

Segment F. First steady-state period—E_R is at a minimum in this area as the water/chemical affects the combustion rate. As the water evaporates, flaming increases except when there is sufficient chemical on the fuel to strongly affect pyrolysis. If the total application of solution is enough to penetrate to the smoldering fuels the flaming will be suppressed even longer or stopped.

Segment G. Second steady-state period—most, if not all, of the water is evaporated and E_R begins to increase. Water-only treatments are totally evaporated in this area and the E_R rate approaches that of untreated fuel.

Segment H. Approximately 75 percent of fuel has been consumed—most of the water has evaporated, chemical effects on pyrolysis are minimal. H to I is mostly smoldering combustion with some short reflaming caused by glowing combustion underneath the surface. E_R for lower water treatments is the same as untreated. Increased water treatments and middle to heavy chemical treatments cause H to I to stay above the untreated total weight loss, but the curve shapes are similar, indicating weight loss is caused by smoldering combustion below the fuel bed surface.

RESULTS

Data from eight test fires were selected to demonstrate how this application method and E_R interpretation can be used to quantify the fire-extinguishing effects of water and retardant. Table 1 shows the application data and resultant E_R modifications. The letter A designates water; B is 10 percent monoammonium phosphate (MAP); and C is 15 percent MAP. X, Y, and Z designate water and retardant mixtures thickened with polysaccharide to 1 cP, 55 cP, or 900 cP viscosities (measured with No. 3 and No. 4 spindles using a Brookfield viscometer at 60 r/min).

Steady-state E_R and duration are determined from straight-line weight loss on the curves. Untreated fires have only one steady-state period, during maximum E_R. All the treated test fires reported here have at least three steady-state periods: one during maximum weight loss before retardant application, one just after the application has stopped, and at least one before the weight loss rate begins to decrease steadily and continue to burn out.

To isolate the effects of retardant viscosity on E_R, application of total weight of water and retardant chemical were held constant. Differences between E_R magnitudes and durations before and after treatments were compared for fires BX216, BY216, and BZ216. Two hundred and forty grams of 10 percent MAP solution were applied with 1 cP, 55 cP, and 900 cP viscosities. BX216 (1 cP) reduced E_R (1st steady-state) by 97.0 percent, BY216 (55 cP) by 97.5 percent, and BZ216 (900 cP) by 93.5 percent. The most obvious difference is between the high viscosity retardant, BZ216, and the low viscosity solutions.

Examining the weight loss curves (fig. 3), we see that BY216 application lowered E_R to a steady-state 7.7 Btu/s (about the same as untreated after fire had burned for 10 minutes) for about 2.80 minutes. The E_R then increased to 15.6 Btu/s for 2.08 minutes before starting a slow decrease in rate until burnout. In comparison, BX216 burned at 9.3 Btu/s for 2.35 minutes then increased sharply to 19.7 Btu/s for 2.28 minutes before burnout. BZ216 burned at 18.8 Btu/s for 2.15 minutes then increased to 34.8 Btu/s for 4.02 minutes.

The effects of retardant chemical on E_R reduction, with total volume of water and viscosity of liquid held constant, can be found by comparing fires AY216, BY216, and CY216. Treatment BY216 (24 g MAP) reduces E_R by 97.5 percent, AY216 (no MAP) by 84.5 percent, and CY216 (38 g MAP) by 98.1 percent. Penetration should be about the same for all because liquid volume and viscosity are identical. In this case, the more retardant chemical added, the more the E_R reduction. An additional 14 g of MAP did not proportionally increase the effectiveness of the treatment but did extend the time of effectiveness.

Examining the weight loss curves (fig. 4) we see that CY216 application reduces E_R to a steady-state 5.4 Btu/s for 5.22 minutes, then increases to 15.6 Btu/s for

Table 1.—Treatment data and resultant energy release modifications for each burn

	Treatment			Energy release rate						
					First steady-state			Second steady-state		
Designation	Water	MAP	Viscosity	Before treatment	Btu/s	Reduction	Duration	Btu/s	Reduction	Duration
	-- Grams	*---*	*cP*	*Btu/s*		*Percent*	*Min*		*Percent*	*Min*
BX216	216	24	1	308	9.3	97.0	2.35	19.7	93.6	2.28
BY216	216	24	55	308	7.7	97.5	2.80	15.6	94.9	2.08
BZ216	216	24	900	289	18.8	93.5	2.15	34.8	88.0	4.02
BY180	180	20	55	280	7.7	97.2	3.13	17.2	93.9	1.73
BY144	144	16	55	308	12.4	96.0	3.05	39.3	87.2	2.03
AY216	216	0	55	330	51.0	84.5	1.28	115.0	65.2	1.03
CY216	216	38	55	280	5.4	98.1	5.21	15.6	94.4	4.88

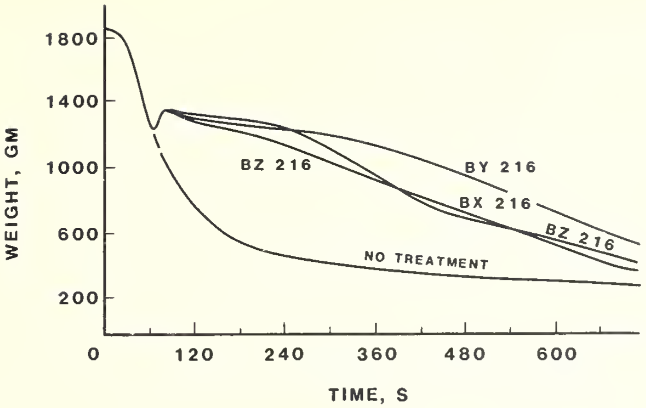

Figure 3.—Fuel weight loss traces when viscosity was varied.

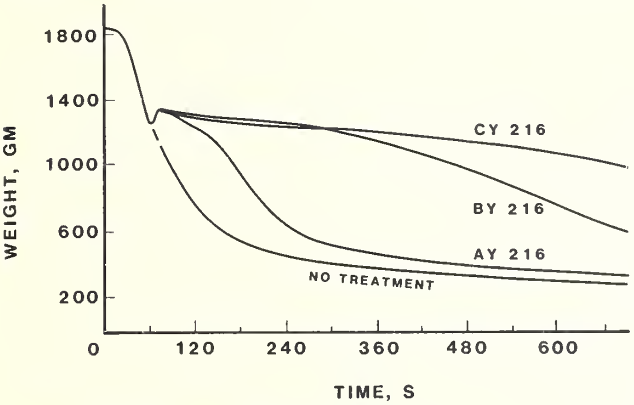

Figure 4.—Fuel weight loss traces when retardant chemical was varied.

4.88 minutes. AY216 reduces E_R to 51 Btu/s for only 1.28 minutes, then increases to 115 Btu/s for 1.03 minutes. (BY216 is listed previously.) The three curves clearly show that compared to water alone addition of MAP significantly reduces E_R and lengthens the time of various levels of energy release.

The effects of retardant volume on reduction of E_R, when viscosity (55 cP) and liquid concentration (10 percent) are constant, can be seen by comparing fires BY144, BY180, and BY216. Treatment BY216 (240 g) reduces E_R by 97.5 percent, BY180 (200 g) by 97.2 percent, and BY144 (160 g) by 96.0 percent. In this comparison, each higher total volume results in a slightly lower E_R.

Examining the weight loss curves (fig. 5) we see that BY144 decreases E_R to 12.4 Btu/s for 3.05 minutes, then E_R increases to 39.3 Btu/s for 2.03 minutes. BY180 decreases E_R to 7.7 Btu/s for 3.13 minutes, then E_R increases to 17.2 Btu/s for 1.73 minutes (BY216 is listed previously). The most obvious differences occur after about 5 minutes; the higher the total volume of liquid applied, the lower E_R remains through burnout.

SUMMARY AND CONCLUSIONS

For the purposes of this study, combustion recovery is defined as flaming and smoldering that can recur shortly after combustion appears to have been suppressed by

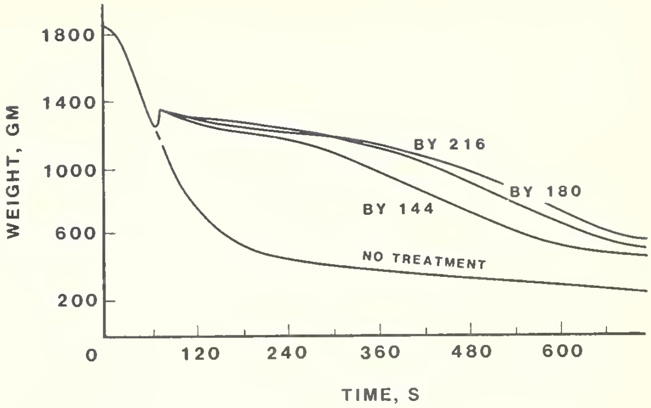

Figure 5.—Fuel weight loss traces when water amount was varied.

fire retardant. Combustion recovery was used in this study to compare the fire-extinguishing abilities of different fire retardant characteristics and was measured in terms of energy release rate (E_R) of burning pine needles. E_R was calculated from steady-state segments of fuel weight loss curves recorded as treated and untreated fuels burned under controlled conditions. Steady-state E_R and duration were used to quantify fire-extinguishing abilities of three different fire retardant characteristics, total volume of liquid applied, viscosity, and weight of retardant chemical. Seven treatments of experimental fires were selected to demonstrate how this method can be used to quantify effectiveness differences.

When total weight of water and amount of retardant chemical were held constant, the weight loss curves showed differences in E_R caused by the retardant viscosities, 1 cP, 55 cP, and 900 cP. From previous studies we know that at higher viscosities retardants form larger droplets that are more likely to penetrate the flame plume. Results of this study indicate that the slightly viscous water and retardants reduce E_R of combustion recovery slightly more than unthickened or high-viscosity liquids. Although the high-viscosity liquids penetrate the flame plume better than low-viscosity ones, in this mat-type fuel bed they may not penetrate as deeply into the smoldering fuel levels and, thus, not coat as much fuel. This theory can be studied more thoroughly in future experiments.

The effects of retardant chemical on reducing E_R were studied by holding volume of water and liquid viscosity constant. The steady-state E_R curve segments can be used to show definite differences between retardant chemical applications; the more retardant applied, the more E_R is reduced. Although in these examples the highest treatment was twice as heavy as the next lower, the reduction in E_R was only slightly more, but the duration was twice as long. The addition of an equal amount of water with no chemical was almost 10 times less effective than either water chemical treatment.

The effects of total liquid weight were studied by holding viscosity and liquid concentration constant and varying the weight of liquid applied. In the examples shown here, the larger the treatment the larger the decrease in E_R and the longer its duration.

Selected data from this method of measuring the combustion recovery can be used to quantify the E_R reduction caused by different fire retardant characteristics. The different fires and treatments were used only to evaluate the method and were not replicated and evaluated statistically, but the limited data show that real differences can be quantified for the different variables. Replications of treatments and fires with different fuel types and environmental conditions are needed to fully study the effects of retardants on combustion recovery and extinguishment.

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Blakely, Aylmer D. Combustion recovery: a measurement of fire retardant extinguishment capability. Research Paper INT-352. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 6 p.

Proposes a method for quantifying the fire-extinguishing capabilities of plain water and water with thickeners and fire-retarding chemicals added. Flaming pine needle fuel beds were sprayed with different water/chemical combinations while energy release rates were continuously monitored before and after treatment. Discusses the action of common retardant formulations and specific ingredients.

KEYWORDS: fire retardant, extinguish, energy release, combustion recovery

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-353

December 1985

The Delphi Method: Application to Elk Habitat Quality

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RESEARCH SUMMARY

Forest Service decision-making processes frequently need information that cannot be adequately met with existing knowledge and data, yet field data collection is often infeasible or untimely. Certain nonfield methods can provide defensible, timely information. Delphi is one such method.

Eleven elk habitat experts served as participants in our Delphi study. Each participant evaluated the summer cover quality of 171 elk habitat settings by rating them on a scale of 1 to 7 and recording their reasons for the ratings. These evaluation bases were then made known to all participants, who could then reassess their original judgments. This process of evaluation, feedback, and reevaluation was made (iterated) three times to obtain final summer cover ratings, and again to obtain summer forage quality ratings. Study results consist of habitat quality ratings and evaluations of the Delphi process.

Habitat quality ratings ranged from "very low" to "very high," with frequency forming a bell shape for both summer cover and forage quality. The quality of elk summer cover was highly related to the structure of site vegetation—tree size and stand density. Summer forage quality was highly related to the type of vegetation on the site—vegetation cover type and forest habitat type. Discriminant functions were developed capable of correctly classifying up to 90 percent of the sites into habitat quality classes based on site characteristics.

We also evaluated the Delphi process. The 11 research participants each devoted an average of slightly over 13 hours to this study. Significant improvements in participant agreement (consensus) on habitat quality ratings were achieved by means of the three-iteration process, but the median rating for each of the 171 settings rarely changed. No statistically significant difference was found in consensus between participants on the basis of their occupational status, expertise, or experience. However, a small but statistically significant difference was found between habitat quality ratings of managers/administrators and researchers/academics. Participants indicated satisfaction with the Delphi process and confidence in the habitat quality ratings.

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ACKNOWLEDGMENTS

The authors wish to express their appreciation to the elk habitat experts who participated in this study. Without their continued commitment of time and talent, this study could not have been completed. We also wish to thank Dr. Hans R. Zuuring, biometrician at the School of Forestry, University of Montana, for his generous support and assistance that helped us get over the many tough spots.

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The Delphi Method: Application to Elk Habitat Quality

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INTRODUCTION

Managers in the USDA Forest Service, like those in other public resource management organizations, are required to base decisions on careful evaluations of management actions. To ensure thoroughness in evaluation, a wide range of consequences are typically assessed, such as national economic development, environmental quality, regional development, and social well-being. To ensure consistency, comparability, and integrity in evaluations, formal procedures are adopted, sometimes requiring the use of sophisticated mathematical models. As a result, more, better, and different kinds of data, relationships, facts, and figures are needed. More than ever before, information fuels the furnaces of decision making.

But like money, information does not grow on trees. Information must be gathered by people using some process. Resource scientists extract information from data gathered through use of the scientific method, along with rigorously controlled experimental designs and meticulously collected measurements. Unfortunately, the constraints of scientific research often lead to information that is "too little, too late." When review of the scientific literature fails to provide needed information, resource managers gather their own, frequently employing procedures that emphasize speed and simplicity—"quick and dirty." While information so generated satisfies the data requirements of mathematical models, too often it lacks the scientific credibility needed to defend results.

Choice between information-generating methods need not be limited to "too little, too late" or "quick and dirty." A number of techniques currently exist whereby timely and credible information can be developed, namely the Nominal Group Technique and the Delphi Method. Both techniques produce information by systematically exploiting the opinions, ideas, experience, and knowledge of individuals, and neither technique involves onsite field measurements. The Delphi Method differs from the Nominal Group Technique by not requiring a face-to-face meeting of the group participants. This feature has two important implications. First, participants are not unduly influenced by the status or personal style of any other participant. Second, because participants need not congregate in one place, Delphi avoids the time and expense of travel and, consequently, can be relatively inexpensive to apply.

Delphi is not a panacea for all information woes. Indeed, there are instances where Delphi is inappropriate or where some other technique may be preferable. But Delphi does hold the promise of being able to provide quality information over a wide range of topics important to natural resource managers. The biggest impediment to application of Delphi may well be its lack of exposure. Resource managers are simply unacquainted with it.

This paper reports on the results of a study designed both to gather important information through Delphi and to evaluate several key features of the Delphi process. We intend to present information developed, and also describe and discuss Delphi so as to make resource managers more comfortable with it, aware of its potential, and willing to consider it along with other information gathering tools.

This study focuses on the quality of elk habitat in western Montana and the Delphi Method. We not only wanted to better understand elk habitat but the Delphi Method as well. Elk habitat quality data were developed through a Delphi process and then these data were assessed: (1) to determine the effect of vegetation type and structure on habitat quality; (2) to determine the effect of site-specific factors, such as temperature and moisture, on habitat quality; and (3) to develop a technique for assigning a quality rating to a habitat setting. These data were also assessed from several standpoints pertaining to Delphi—effect of iteration and number of participants on consensus, participant selection, and more.

METHODS

Because the methods used in this study are more confusing than complicated, it is best to separate discussion of the Delphi-oriented methods and the analytical methods used. The discussion is somewhat artificial in that while these methods are presented separately, they are in reality interconnected.

Delphi Methods

Delphi was developed by the RAND Corporation as a systematic tool for harnessing group knowledge pertaining to a wide range of program planning matters (Dalkey 1969). Delphi has three main features (Delbecq and others 1975): it uses written responses, participants typically remain anonymous, and the process uses a series of questionnaires to clarify areas of agreement and disagreement. Delphi aims to promote group consensus on some topic or issue by extending the adage that "two heads are better than one." Several heads are used. Consensus is not achieved immediately, if ever. Improvements in consensus result from an iterative process wherein participants assess an issue, document or justify their assessment, and are given opportunity to reassess their earlier position in light of information from other participants.

The several methodological components involved in this study are illustrated in figure 1. This and the next section discuss each component: the topic and why it was selected; how participants were identified and selected; the questionnaire or data-gathering instrument; how feedback was provided to the participants; the exit interview questionnaire used to conclude data collection; and a general description of the methods used to analyze data.

The Topic—Elk Habitat.—The range of topics to which Delphi can be applied is wide. Although almost any topic would do, we wanted to assess one representing an actual information need relevant to forest managers. We also wanted a topic of sufficient scope and complexity to be judged nontrivial, yet manageable. We considered topics from timber management, recreation management, wildlife management, and so on. The one we eventually selected involved measuring the quality of elk (*Cervus elaphus nelsoni*) summer forage and summer cover in Montana west of the Continental Divide. Although winter range is often considered a limiting factor for elk, summer habitat was selected for study because National Forest System lands contain a substantial portion of elk range that is predominantly summer range. Thomas (1979) describes forage as vegetation used for food by wildlife; cover is vegetation used by wildlife for protection from predators, to ameliorate conditions of weather, or in which to reproduce. No distinction was made between thermal (from heat) and hiding (from predators) cover.

Montana west of the Continental Divide was selected as the study's geographical scope because it is a major elk-producing area, and elk habitat considerations are often critical in forest management. The area is also large enough—western Montana is roughly the size of West Virginia—that obtaining similar information from field measurements would be essentially infeasible. Finally, the study area is relatively homogeneous ecologically.

Participant Selection.—As with any group process, Delphi requires participation by a set of individuals. The type of participants used in a Delphi project should depend on the nature of the topic being addressed. The topic of elk habitat quality called for participants with a specialized, technical knowledge consistent with the term "experts," recognized authorities on elk habitat. Unfor-

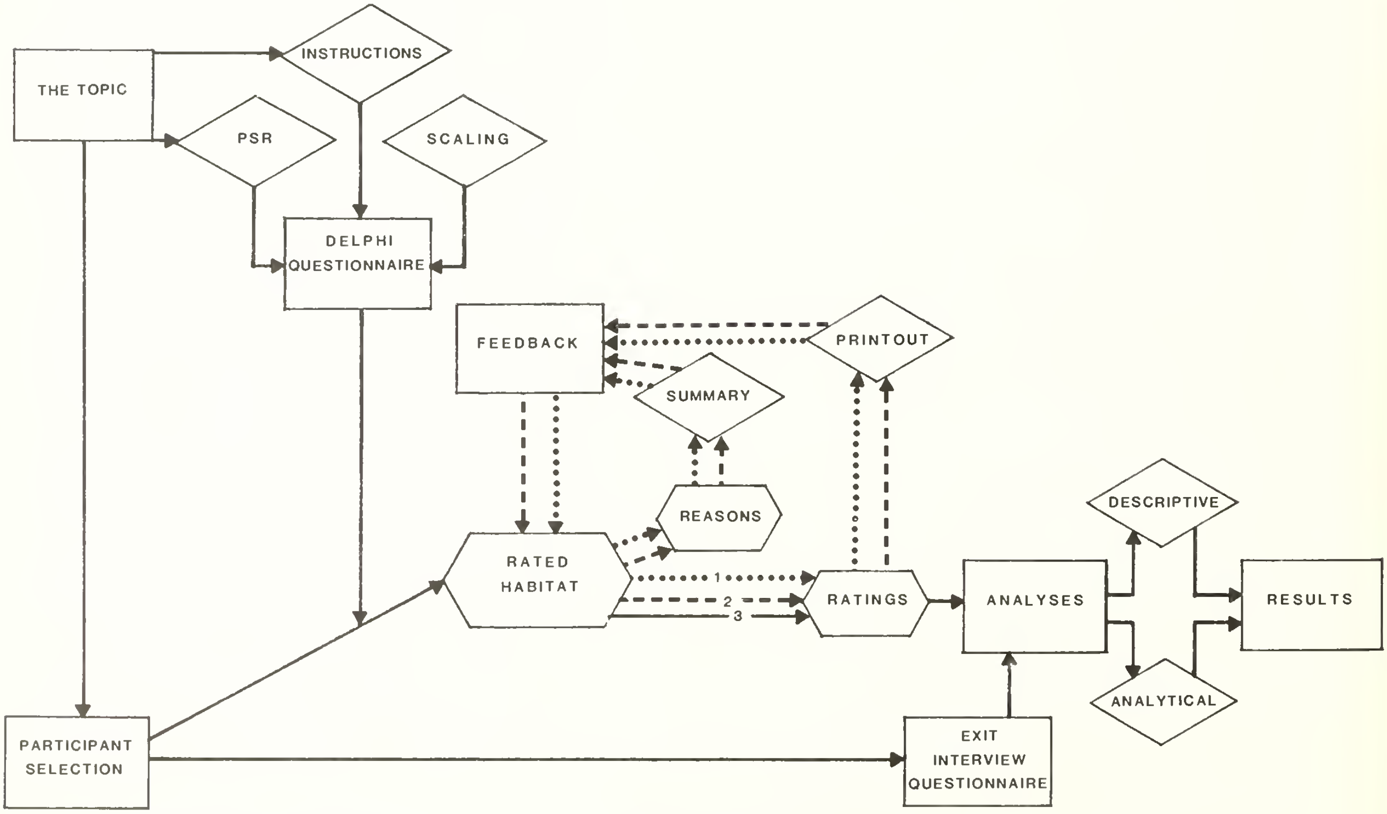

Figure 1.—Flowchart of study methodological components and their linkages.

tunately, because there is no directory of elk habitat experts, we needed to identify them ourselves.

Numerous direct and indirect ways exist for identifying elk habitat experts. We developed a composite procedure that actually consisted of several methods. The approach used could be called "networking," being similar to that used in sociological studies to identify a community's power structure (see, for example, Domhoff 1978).

Based on the study team's perception of people with substantial knowledge in elk habitat, a "starter" was selected. We attempted to identify a knowledgeable person who would not likely be judged by others as an expert. That person was interviewed and asked to list all experts on elk habitat management in western Montana:

> . . . Please identify all individuals that you consider to be experts. They may be from any occupational status, such as managers, teachers, administrators, researchers, or from the lay public. They need not be physically located in western Montana, but must be knowledgeable about it. Please include yourself, if appropriate.

The starter was then instructed to rank the identified persons in terms of the degree of expertise, from most to least, paying particular attention to correctly specifying the order of the top-three persons. Each of the top-three experts from the starter's list was then contacted and asked to identify and rank all experts, again paying particular attention to the order of the top three. All new top-three experts were then contacted and the process was continued until no new top-three experts were identified. This procedure was adopted so that we could later compare the ability of different approaches to identify experts.

To ensure procedural consistency, a standard interview format was always used. All interviews were either conducted in person or by telephone. Each individual contacted was free to use personal criteria for judging an expert. As was the case throughout the entire study, individuals were given the assurance of anonymity, that their identity and organizational affiliation would be held in the strictest confidence.

The Data-Gathering Instrument.—Any Delphi exercise must use some method to address the topic and obtain measurements—a data-gathering instrument. Although in Delphi this instrument is called a questionnaire, it need not look like a normal questionnaire. In our case, the data-gathering instrument consisted of pictorial site representations (PSR's), a scaling or classification procedure, and a set of instructions.

If this were a field study, actual measurements would be made on a site. The PSR's depicted conditions that might be found on an actual site. We identified 171 specific elk habitat settings (discussed later) representing various combinations of (1) vegetation cover type, and if forested, (2) groupings of forest habitat types (Pfister and others 1977), (3) tree size, and (4) stand density or stocking. For example, one of the 171 settings was a well-stocked stand of sawtimber-sized lodgepole pine trees growing on a spruce habitat type. There were 171 PSR's, one for each elk habitat setting.

Figure 2 shows that each PSR consisted of a written description of the vegetation and its environment, a black and white sketch showing a cross-sectional view of the vegetation, and an illustrative, color photocopy. Substantial thought went into the content and format of the PSR. The result represented a compromise between what was desired and what was physically and financially possible. For example, we wanted to use color prints exclusively, but they were prohibitively expensive. Similarly, while we wanted to use two photographs (near and far view), we could not accumulate a satisfactory set of photographs for all 171 elk habitat settings. Therefore, only near-view photographs were used.

The study team produced the PSR's. We obtained many color photographs from existing print and slide collections. If the needed photographs were either inadequate or not available, a study team member traveled to appropriate sites and took the photographs. An artist knowledgeable in vegetation structure drew the black and white sketches. The written descriptions were based on Pfister and others (1977). Initial descriptions were reviewed and revised by Robert D. Pfister. We assembled all materials into a master set. A local commercial operator duplicated the master set on heavyweight bond paper for each participant.

A scaling procedure was designed to classify PSR's into habitat quality groups, thereby providing a measurement of the quality of each PSR in terms of elk summer cover and forage. We chose to use a modified Q-sort Method (Selltiz and others 1959) and a seven-level scale. We sent each Delphi participant a set of 171 randomly ordered PSR's. The participants were told to look through the PSR's to get a feel for the range of conditions with which they were to work. They were then instructed to place each PSR into one of three groups according to elk habitat quality—high, medium, and low—initially for cover and then later in the study for forage. The high and low quality groups were then further subdivided into two groups, and the middle group was subdivided into three groups. Thus, each PSR was systematically placed into one of seven groups. Numerical codes were assigned to the groups of PSR's according to the following definitions:

Very low	(1)	— The worst sites, with virtually no habitat value
Low	(2)	— Poor, but with minimal elk habitat value
Low medium	(3)	— The poorest of the medium sites
Medium	(4)	— Adequate or average
High medium	(5)	— The best of the medium site
High	(6)	— Somewhat less than best but still high quality
Very high	(7)	— The best sites

Participants were invited to adjust PSR's among groups to ensure that each PSR ultimately corresponded to the group's definition.

Participants were provided with other instructions that promoted consistency. The following instructions are typical, though specifically pertaining to summer cover measurements:

COVER TYPE: LODGEPOLE PINE

Stand Size: Sawtimber (>9" diam.)

Stocking Level: Poorly Stocked (11-40% tree crown cover)

HABITAT:

DOUGLAS-FIR IV - Douglas-fir/blue huckleberry and Douglas-fir/twinflower (blue huckleberry phase) habitat types.

Closed canopy stands on relatively cold sites, usually bordered upslope by subalpine fir types. Stands range from 3000 to 6000 feet in elevation.
Understory dominated by shrubs such as blue huckleberry and spiraea, but also support beargrass.

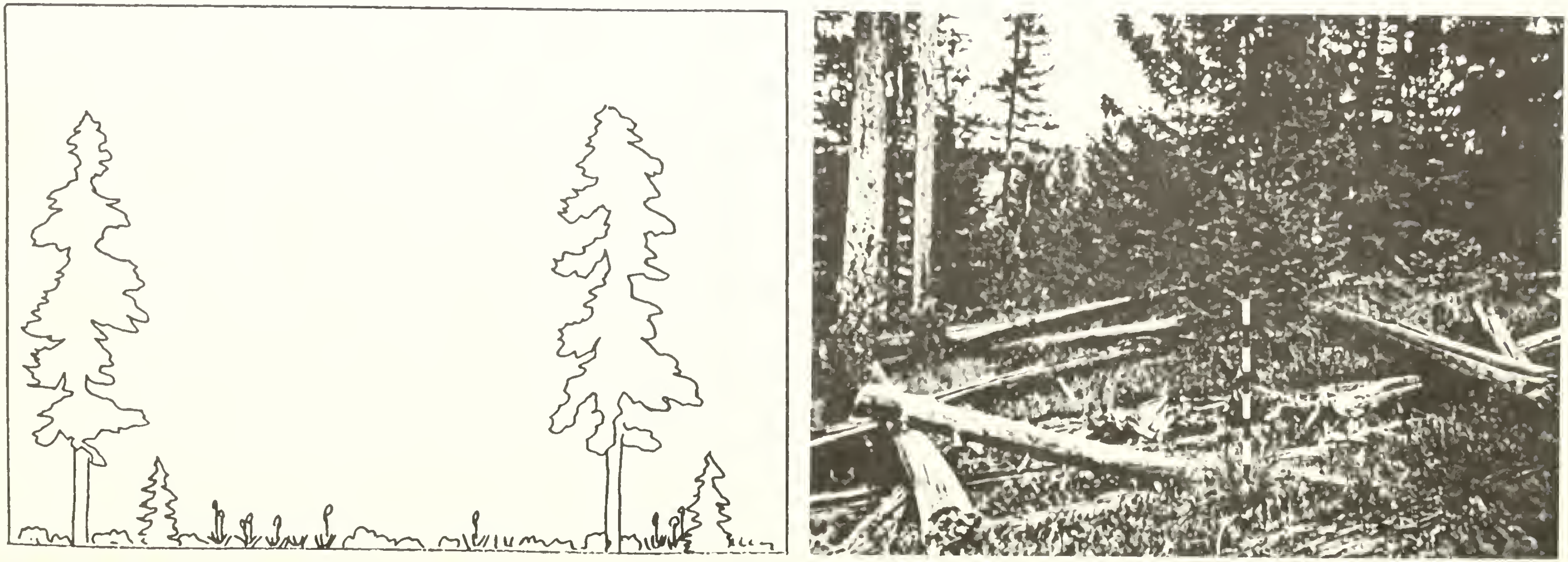

Figure 2.—Illustration of a pictorial site representation (PSR).

1. Your ratings are for elk habitat only.
2. Our concern at this point is for elk summer cover quality in western Montana. Do not complicate the situation by attempting to visualize winter cover, summer food value, and so forth. We are only interested in how valuable each site is for providing cover for elk during midsummer, prior to any range shifts that might occur due to the onset of the rut.
3. Remember that each PSR illustrates a specific site condition. Try to keep the general site characteristics in mind when doing the rating and don't get led astray by some minor peculiarity of a particular photo.
4. We are assuming there are no active roads in the vicinity and there has been no timber harvesting or other stand manipulation.
5. The PSR's are designed specifically to represent a range of conditions common in the forests of Montana west of the Continental Divide and should be evaluated in terms of that area.

Each participant was also provided a form on which to keep track of the time spent on aspects of the study. Participants were instructed to complete all tasks and return all material (in a stamped return envelope) by a specified date, usually about 2 weeks. Finally, participants were instructed not to discuss this study or their involvement with others.

Feedback.—A Delphi process is designed to promote group agreement (consensus) on a topic. This is accomplished by "controlled feedback" and "iterations." The feedback process allows participants to share with each other their personal basis for the judgments. The iteration (repeating) process allows participants to reassess their prior individual judgments in light of the summarized information (reasons, opinions) provided by all participants. There are two important aspects to the feedback process. One relates to acquisition of information by the study team and the other deals with presentation of summarized information to the participants. There is no standard format to provide feedback in Delphi. It must be tailored to the situation.

The study team devoted many hours to discussing alternative types of feedback. We selected two. One type involved summarizing the bases participants used for their judgment. The other type of feedback involved providing each participant with some quantitative information on how the PSR's were rated by other participants. Because all ratings were stored in computer data files, the study team already had information on how the PSR's were rated. The reasons given by participants for rating PSR's were obtained by a short questionnaire. When completed, the questionnaire provided the study team with a listing of the common characteristics associated with the PSR's in each category. The following directions were provided:

> . . . In the spaces provided, please list (complete sentences) up to three statements you would use to characterize the common elements represented by PSR's in quality category 1, quality category 2, and so forth. For example, "all PSR's in category 1 are very open, young stands with little crown cover."

Collecting feedback information was considerably easier than communicating it back to the participants. After all sets of reasons (common elements) were received from each participant, the reasons were evaluated by "content analysis" procedures (see Bowers 1970) to further identify common features. After several trials, content analyses were judged too unwieldy and were discontinued. To condense exhaustive amounts of written information into a manageable form, the study team chose to summarize stated reasons in the form of summary evaluations. One set of reasons was developed and provided to each participant. Each set consisted of seven pages, one for each rating category. Each page contained information in five categories—tree cover, tree size, habitat type, cover type, and other features. The order in which these categories appeared on a summary evaluation page was varied so as to preclude any bias introduced by a consistent order. A partial illustration of a page follows:

Category 1 - Very Low - Forage
I. Tree cover:*
  Nonstocked— 20%
  Poorly stocked— 35%
  Medium stocked— 10%
  Well stocked— 0%
  .
  .
  .
V. Other:
  Poor soils— 20%
  Vegetation dries early— 20%

*Percentage indicates proportion of experts using or mentioning the characteristic in their reasons.

The study team carefully considered how to best communicate quantitative information about how the PSR's were rated. The issue was not to provide a comparison showing PSR ratings and how an individual participant related to others. Rather, the issue pertained to the amount of detail. Arguments against detail were based on the fear of exerting too much pressure on the participants to conform. Arguments in favor of detail were based on the premise that a participant is more likely to modify a judgment if that judgment is perceived to be nonconforming. We adopted the more detailed approach. Each participant was provided a computer printout of the ratings (rating printout), as partially illustrated:

	All experts combined				
PSR	Low	High	Median	Your rating	Difference
1	2	4	4	3	−1
2	4	4	4	4	0
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
171	6	7	6	6	0

The summary evaluations and the rating printouts constituted the feedback provided to each participant after the initial rating. Consistent with contemporary

Delphi literature and application, each interaction (including the first) with participants constitutes an "iteration." By convention, the first iteration has no feedback.

In principle, the number of iterations used in a Delphi project is open-ended, determined on the basis of some prespecified level of consensus desired. The iterative process continues until the consensus standard is met. But because we wanted to measure the effect that the number of iterations had on consensus, several iterations were needed. Because we did not believe the experts would agree to participate in a process with no finite limits, we decided to use three iterations for both the elk summer cover phase and the forage phase. This amount represented our judgment as to the minimum number of iterations needed to measure the effect of iterations on final consensus and the maximum burden we could reasonably place on the participants.

All feedback materials, and the 171 PSR's as previously sorted, were returned to each participant to begin the second iteration. The second iteration consisted of each expert reassessing first iteration judgments in light of the feedback materials. Individual PSR's were shifted from one habitat quality group to another. When reassessments were completed, participants again recorded their reasons and returned the materials. The process was iterated for a third time, thus completing the summer cover phase. The entire three-iteration process was repeated for summer forage.

Exit Interview Questionnaire.—After all habitat quality data had been gathered, the study team wanted to know the participants' reactions to the Delphi process. What were the strengths and weaknesses? Were seven Q-sort groups too many? Was the feedback adequate? These and other concerns were addressed in an exit interview questionnaire, available on request from the authors. The questionnaire was mailed to participants. Upon return of all questionnaires, data collection was complete and final analyses were started.

Analytical Methods

This section briefly describes the variables, methods, and conventions used to design the study and analyze the data. It does not provide enough detail to duplicate the analyses, but rather enough for the reader to develop a general comprehension. More details pertaining to analytical methods will be provided later, as appropriate, along with study results.

Variables.—This study used two classes of variables—primary and secondary. The primary variables resulted directly from the main thrust of the study, were the basis for the study's experimental design, and specified the way PSR's were characterized. Table 1 identifies and defines primary dependent and independent variables. All variables are measured on either nominal or ordinal scales, with analytical implications that will be discussed later.

The primary dependent variable used in this study consists of elk summer cover and forage quality ratings. For purpose of conducting statistical or numerical analyses, the habitat quality ratings were assigned numerical values ranging from 1 for very low to 7 for very high. Measures of central tendency for this type of ordinal scale data include the median (middle) and mode (most frequent) rating, but exclude the arithmetic mean. This study used the median rating to reflect a PSR's final, overall rating. The median was also used as a basis to reflect both variation in habitat ratings and consensus. We used the average or mean deviation from the median (MDM) as our measure of variation and consensus. This is calculated by summing the (absolute) deviations from the median over all participants and dividing by the number of participants. The higher this number, the more variation around the median. MDM is comparable to an unsquared version of the "variance" used in conjunction with a mean. If all 11 experts rated a situation as "medium" (4), the median would be 4 and the mean deviation from the median would be 0, thus achieving unanimity, complete agreement, or perfect consensus.

The forest habitat type group variable was created by the study team. To use all of the individual forest habitat types would have been too cumbersome and unnecessarily specific for our purpose. Therefore, the individual forest habitat types identified by Pfister and others (1977) were grouped into 18 habitat type groups. These are presented in appendix A, along with their constituent forest habitat types. The grouping represents a slight modification and updating of an elk habitat group scheme developed by Forest Service wildlife managers for use in western Montana (USDA Forest Service 1980).

While the forest habitat type group variable and the vegetation cover type variables can be used separately, we frequently combined them. These combinations correspond to major natural occurrences of habitat type groups and cover types in western Montana. Table 2 shows the 37 naturally occurring combinations of our 18 forest habitat type groups and 12 vegetation cover types. Depending on the purpose, some analyses used the combinations, while others used either the 18 habitat type groups or 12 cover types separately.

Similarly, combinations of tree size class and stand density classes were developed. Tree size (TS) was divided into three classes: seedling/sapling (S/S), poletimber (Pole), and sawtimber (Saw). Stand density (SD) was also divided into three classes: poor, medium, and well stocked. The ideal would have been an elk habitat represented by all possible combinations of tree size and stand density classes. This proved infeasible for two reasons. First, not all combinations of size and density occur naturally. An example is the poorly stocked seedling-sapling stands of western redcedar, a combination that basically does not naturally exist. Second, we wanted to keep the participants' workload within reason, and all combinations seemed unreasonable. To simplify matters, we adopted five combinations, instead of the potential nine:

Stand	Tree size class		
density class	S/S	Pole	Saw
Poor	X		X
Medium		X	
Well	X		X

Table 1.—Description of dependent and independent variables used in study

Type of variable	Name of variable	Measurement scale	Code or attribute	Definitions
Dependent	Cover quality and forage quality	Ordinal	1 or VL	Very low: worst sites, with virtually no habitat value
			2 or L	Low: poor, but with minimal elk habitat value
			3 or LM	Low medium: poorest of the medium sites
			4 or M	Medium: adequate or average
			5 or HM	High medium: best of the medium sites
			6 or H	High: somewhat less than the best but still high quality
			7 or VH	Very high: the best sites
Independent	Forest habitat type groups	Nominal	1 – 18	Groups of forest habitat types. (An aggregation of all land areas potentially capable of producing similar plant communities at climax; Pfister and others 1977)
Independent	Vegetation cover types	Nominal	1 – 12	Existing overstory vegetation. If forested, based on species forming a plurality of live-tree stocking (Green and Setzer 1974)
Independent	Tree size class	Ordinal or nominal	—	A classification of forest land based on size classes of growing stock trees on the area
			—	Stands at least 16.7 percent stocked with growing stock trees, with half or more of stocking . . .
			Sawtimber	. . . in sawtimber or poletimber trees, and sawtimber stocking at least equal to poletimber stocking (sawtimber trees are ≥9.0 inches dbh)
			Poletimber	. . . in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber (poletimber trees are >5.0 to <9.0 inches dbh)
			Seedling and sapling	... in saplings or seedlings (seedling and sapling trees are ≤5.0 inches dbh)
Independent	Stand density class	Ordinal or nominal	—	A classification of forest land based on the density of trees on the area
			Poor	11 to 40 percent crown cover, or 16.7 to 60.0 percent normal stocking
			Medium	41 to 70 percent crown cover, or 60 to 100 percent normal stocking
			Well	71 to 100 percent crown cover, or 100 to 133 percent normal stocking

Because all treatment combinations are not present, this study used an incomplete block design. Depending on the purpose, some analyses used the combinations of size and density classes, while others used size or density classes individually, or both.

Let us recap the origins of the 171 PSR's. Of the 37 combinations of habitat type groups and cover types, three were nonforested, and the notions of tree size and stand density were not applicable. These nonforested combinations account for three PSR's. Of the remaining 34 combinations, one occurs only in medium and well-stocked stands; this situation resulted in three PSR's. The remaining 33 combinations could be represented by all five size and density combinations. These account for 165 (5 × 33) PSR's. In total, we used 171 (3 + 3 + 165) PSR's.

A large number of secondary variables were also used in supporting analyses:

Secondary dependent variables	Secondary independent variables
Mean deviation from median	Iteration
Exit interview results	Number of participants
Time record results	Participant characteristics
	Habitat type components

These variables were used both in conjunction with primary variables and separate from primary variables. Many variables listed are actually groups of more specific variables. For example, the answer to each question on the exit interview questionnaire represented a potential dependent variable. Similarly, for several analyses we used six components of habitat type as candidate independent variables—such as elevation, moisture, and temperature. Some secondary variables were measured on a nominal scale, such as habitat type components. But others were measured on a ratio scale, such as time.

Table 2.—Naturally occurring combinations of forest habitat type groups and vegetation cover types

Forest habitat type groups	Vegetation cover type											
	Hardwoods	Ponderosa pine	Douglas-fir	Lodgepole pine	Western larch	Engelmann spruce	Grand fir	Western redcedar	Subalpine fir	Whitebark pine	Forbs and grasses	Shrubs
Bottomlands	x											
Ponderosa pine		x										
Scree		x	x									
Douglas-fir I		x	x									
Douglas-fir II		x	x									
Douglas-fir III		x	x	x								
Douglas-fir IV			x	x								
Douglas-fir V		x	x									
Spruce	x			x		x						
Western redcedar/ grand fir							x	x				
Subalpine fir I			x	x	x	x						
Subalpine fir II				x		x			x			
Subalpine fir III				x					x	x		
Subalpine fir IV				x		x			x			
Whitebark pine										x		
Mountain meadow											x	
Mountain grassland											x	
Mountain brush												x

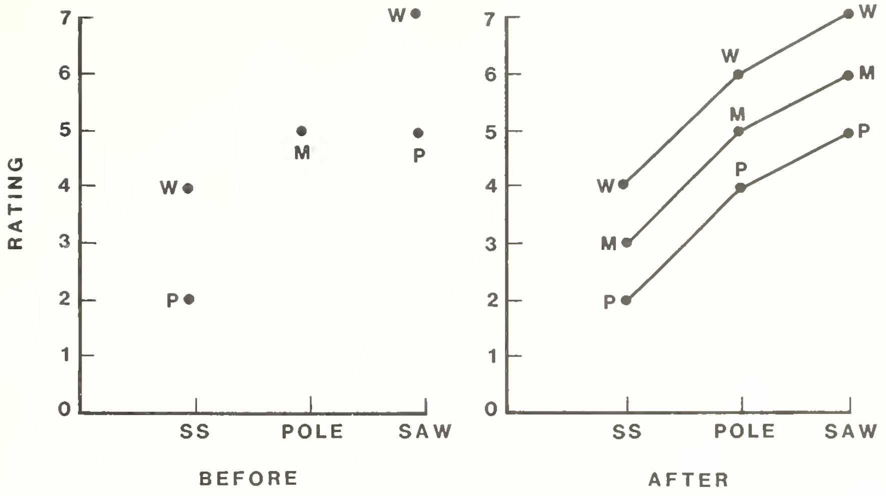

Figure 3.—Illustration of habitat quality ratings, before and after application of interpolation technique.

Ordinal-Level Data Interval-Level Analyses.—Table 1 indicates that habitat quality is measured on a seven-level ordinal scale—very low to very high. Considerable controversy exists concerning the appropriate statistical tests, models, and arithmetic operations that can be performed on ordinal data (see Kirk 1972). Specifically, researchers who have ordinal-scale data would like to apply analytical techniques compatible with interval-scale or ratio-scale data. Those techniques offer more choices and can extract more data. Without belaboring this controversy, the opposing viewpoints are: (1) under no circumstances can interval-scale or ratio-scale operations be applied to ordinal-scale data, and (2) go ahead, do it. The study team struck a compromise. Interval-level statistics were used for testing statistical hypotheses. But ordinal-level statistics were used for describing data and study results. Consequently, we used medians (appropriate for ordinal-level data), not means, to describe habitat quality results. But we also used regression and other analyses (appropriate for interval-level data) to investigate underlying habitat quality relationships.

Analyses Used.—Data files were maintained and analyzed through the services of the University of Montana Computer Center and its DEC-20 computer. The main analyses performed were analysis of variance, linear regression analysis, and discriminant analysis. Statistical analyses and data manipulation used computer software available through SPSS-X and Minitab. Except for the method used for interpolation, all other analyses were conducted in conventional ways.

The interpolation method requires additional explanation. Recall that to lessen the burden placed on the participants, PSR's were developed for only five of the nine combinations of tree size classes and stand density classes. A possible array of median habitat quality results is illustrated:

Stand	Tree size class		
density class	S/S	Pole	Saw
Poor	2	—	5
Medium	—	5	—
Well	4	—	7

We felt an obligation to "fill-in-the-blanks." Study team member, Robert S. Loveless, Jr., developed a procedure for doing so. The procedure could be called "two-dimensional interpolation" and is based on the technique of Median Polish (see Velleman and Hoaglin 1981 or Tukey 1977). The procedure works by discovering and then using patterns within arrays. The array shown above has pattern, ordered from left to right and top to bottom. The missing values are numerically between or equal to those on either side, above, or below. All missing cell values are determined by multiplying the percentage diagonal change by the row or column differences and then adding that product to a leftmost or uppermost known value; this result is rounded to the nearest integer. Figure 3 illustrates the result of this interpolation process. The pattern embedded in the original data provides the basis for specifying the overall pattern.

Two final points regarding analysis should be mentioned. First, statistical tests were always conducted at the 0.05 level of significance. Second, the number of observations used in specific analyses frequently varied, depending on the purpose of the analysis. When necessary, observations were eliminated from analyses to achieve balance in experimental design; balance here refers to a situation where there is an equal number of observations in each analysis class or subclass.

RESULTS

During August 1982 the first packet of materials was sent to each participant. By August 1983 all data had been collected for summer cover and summer forage and the exit interview questionnaire had been completed. Results are divided into two sections—Elk Habitat Quality and the Delphi Process.

Elk Habitat Quality

This section describes the results of elk habitat quality ratings and provides results from three major types of analyses pertaining to those ratings. The first analysis assessed elk habitat quality as related to forest habitat type groups, vegetation cover type, tree size, and stand density. The second analysis assessed habitat quality from the standpoint of the underlying components of forest habitat type, such as site elevation and moisture. The third type of analysis developed a tool by which elk habitat settings can be classified or assigned to a habitat quality class based on site characteristics.

Descriptive Results.—The final measure of elk habitat quality is the median rating associated with the third iteration. Table 3 shows these medians expressed as letter designations (such as L for low), along with interpolated results for elk summer cover and forage. For both cover and forage, results for the 171 settings spanned the quality range from very low to very high. A comparison between cover and forage ratings, for an individual setting,

Table 3.—Final elk summer cover and forage quality ratings, by vegetation cover type, forest habitat type group, stand density class, and tree size class

			Tree size class					
			Cover			Forage		
Vegetation cover types	Forest habitat type groups	Stand density class	Seedling/ sapling	Pole-timber	Saw-timber	Seedling/ sapling	Pole-timber	Saw-timber
Hardwoods	Bottomlands	Poor	L	LM	M	HM	M	M
		Medium	LM	M	HM	M	M	M
		Well	LM	HM	H	M	M	M
	Spruce	Poor	LM	LM	M	VH	VH	H
		Medium	LM	M	HM	VH	VH	H
		Well	LM	M	H	VH	VH	H
Ponderosa pine	Ponderosa pine	Poor	VL	L	M	L	L	L
		Medium	VL	L	M	L	L	L
		Well	L	LM	M	L	L	L
	Douglas-fir I	Poor	VL	L	LM	L	L	L
		Medium	L	LM	M	L	L	L
		Well	L	LM	M	L	L	L
	Douglas-fir II	Poor	LM	M	M	LM	LM	LM
		Medium	LM	M	HM	LM	LM	LM
		Well	LM	M	HM	LM	LM	LM
	Douglas-fir III	Poor	VL	LM	M	M	LM	LM
		Medium	LM	M	HM	M	LM	LM
		Well	LM	HM	HM	M	LM	LM
	Douglas-fir V	Poor	VL	LM	M	L	L	L
		Medium	L	LM	M	L	LM	L
		Well	L	LM	M	L	L	L
	Scree	Poor	VL	L	L	VL	VL	VL
		Medium	L	L	LM	VL	VL	VL
		Well	L	LM	LM	VL	VL	VL
Douglas-fir	Douglas-fir I	Poor	L	LM	LM	L	L	L
		Medium	L	LM	M	L	L	L
		Well	L	LM	M	L	L	L
	Douglas-fir II	Poor	L	LM	M	LM	LM	LM
		Medium	LM	M	HM	LM	LM	LM
		Well	LM	M	HM	LM	LM	LM
	Douglas-fir III	Poor	L	LM	M	M	M	LM
		Medium	L	M	HM	M	M	LM
		Well	L	M	HM	M	M	LM
	Douglas-fir IV	Poor	L	LM	M	M	M	M
		Medium	LM	M	HM	M	M	M
		Well	LM	HM	H	M	M	M
	Douglas-fir V	Poor	VL	LM	M	LM	LM	LM
		Medium	L	LM	HM	L	L	L
		Well	L	M	HM	L	L	L
	Subalpine fir I	Poor	VL	HM	HM	H	H	H
		Medium	LM	HM	HM	VH	H	H
		Well	LM	HM	HM	VH	H	H
	Scree	Poor	VL	L	LM	VL	VL	VL
		Medium	L	L	LM	VL	VL	VL
		Well	L	LM	LM	VL	VL	VL
Lodgepole pine	Douglas-fir III	Poor	VL	LM	M	LM	LM	LM
		Medium	LM	M	HM	M	LM	LM
		Well	LM	HM	HM	M	M	LM
	Douglas-fir IV	Poor	VL	LM	M	M	LM	LM
		Medium	LM	M	HM	M	M	M
		Well	LM	HM	HM	M	M	M
	Subalpine fir I	Poor	L	LM	M	VH	HM	HM
		Medium	LM	M	HM	VH	H	H
		Well	LM	HM	H	VH	H	H

(con.)

Table 3. (Con.)

Vegetation cover types	Forest habitat type groups	Stand density class	Tree size class					
			Cover			Forage		
			Seedling/ sapling	Pole-timber	Saw-timber	Seedling/ sapling	Pole-timber	Saw-timber
	Spruce	Poor	VL	LM	M	H	H	H
		Medium	L	M	HM	H	VH	VH
		Well	LM	HM	H	VH	VH	H
	Subalpine fir II	Poor	L	M	HM	HM	M	M
		Medium	M	H	VH	HM	HM	HM
		Well	M	H	VH	HM	HM	HM
	Subalpine fir III	Poor	L	LM	M	M	L	L
		Medium	L	M	HM	LM	LM	LM
		Well	L	M	HM	LM	LM	LM
	Subalpine fir IV	Poor	L	LM	M	HM	M	M
		Medium	LM	M	HM	HM	M	M
		Well	LM	HM	H	HM	M	M
Western larch	Subalpine fir I	Poor	L	LM	M	VH	H	H
		Medium	LM	M	HM	VH	H	H
		Well	LM	HM	H	VH	H	H
Engelmann spruce	Subalpine fir I	Poor	L	LM	HM	VH	VH	H
		Medium	LM	M	H	VH	VH	H
		Well	M	HM	VH	VH	VH	H
	Subalpine fir II	Poor	L	M	M	H	H	HM
		Medium	M	VH	VH	H	H	HM
		Well	M	VH	VH	H	H	HM
	Subalpine fir IV	Poor	LM	M	M	HM	M	M
		Medium	M	HM	H	HM	HM	HM
		Well	M	H	VH	HM	HM	HM
	Spruce	Poor	LM	LM	LM	VH	VH	H
		Medium	M	HM	HM	VH	VH	H
		Well	M	H	VH	VH	VH	H
Grand fir	Western redcedar/ grand fir	Poor	LM	M	M	HM	HM	HM
		Medium	M	H	H	M	H	H
		Well	M	H	VH	H	H	M
Western redcedar	Western redcedar/ grand fir	Poor	—		M			HM
		Medium	—	M			HM	
		Well	—		VH			HM
Subalpine fir	Subalpine fir II	Poor	M	HM	HM	HM	HM	HM
		Medium	M	H	H	H	HM	HM
		Well	M	H	VH	H	HM	HM
	Subalpine fir III	Poor	VL	LM	M	M	M	LM
		Medium	L	M	HM	M	M	LM
		Well	LM	HM	H	LM	LM	LM
	Subalpine fir IV	Poor	VL	M	HM	HM	HM	HM
		Medium	LM	HM	H	HM	HM	HM
		Well	M	H	VH	HM	HM	HM
Whitebark pine	Subalpine fir III	Poor	VL	LM	M	L	L	L
		Medium	LM	M	HM	LM	LM	LM
		Well	LM	HM	HM	M	M	M
	Whitebark pine	Poor	VL	L	LM	M	M	M
		Medium	L	LM	M	M	M	M
		Well	LM	M	HM	M	M	LM
Forbs and grasses	Mountain meadow	—	—	VL	—	—	VH	—
	Mountain grassland	—	—	VL	—	—	HM	—
Shrubs	Mountain brush	—	—	LM	—	—	M	—

---

[1] Quality ratings in small print were developed by an interpolation process.

shows both consistency and great divergence. Not unexpected, the mountain meadow setting had the greatest rating differences—"very low" for cover and "very high" for forage. On the other hand, the settings containing the scree habitat type received consistent ratings for cover and forage—consistently low.

Inspection of the ratings in table 3 also provides a preview of the analysis results presented later. Note that while the cover ratings generally increase with shifts from poorly stocked seedling-saplings to well-stocked sawtimber, the ratings are far more erratic between forest habitat type groups or vegetation cover types. Similarly, shifts between tree size and stand density classes do not seem to affect forage ratings, while cover type and habitat type groups do.

A general description of habitat ratings would not be complete without some indication of variation in the results. Appendix B contains a complete tabulation of variation levels, as reflected by the mean deviation from the median rating, for all elk habitat settings studied. The average of the mean deviations from the medians for cover was 0.5 and 0.4 for forage. That is, forage ratings were about 20 percent less variable than were cover ratings. Because each unit of deviation represents a class, the average deviations above correspond to about half a class interval. The most variation was found in cover ratings for several cases involving ponderosa pine or Douglas-fir cover types where the mean deviation from the median was 1.1 or more. The least variation (0.0) existed with forage ratings for scree and mountain meadow.

Figure 4 shows a frequency distribution of all 171 elk habitat settings in each habitat quality rating class for both summer cover and forage. These distributions are visibly "normal" in that they resemble a bell-shaped curve. In both cases, the median and modal class is "medium." While the middle five classes show a pattern of consistency between cover and forage, the extreme classes (very low and very high) show opposite patterns. Relatively more elk habitat settings are rated "very high" for forage than for cover (17 versus 6); and relatively more settings are rated "very low" for cover than for forage (16 versus 10).

Vegetation Structure and Type.—This line of analysis sought to determine the influence of the primary independent factors—cover type, tree size, and so forth—and their interactions on elk habitat quality. The main difficulty was that the desired analysis could not be performed directly because the experimental design was not balanced; that is, we did not have an equal number of observations associated with all combinations of levels for the independent variables. Consequently, we had to conduct three analyses that sequentially led to the final results. Desired balance was achieved by eliminating observations. Throughout these analyses, observations from all 11 participants were used. The largest data set contained 1,881 (11 × 171) observations and the smallest contained 1,452 observations.

The first series of analyses were one-factor analyses of variance. Their purpose was to determine which individual factor(s) had the largest and smallest effects on habitat quality ratings. All 1,881 observations were used. Each independent factor or factor combination was used in separate analyses, isolated from other factors. Table 4 combines the results and shows the degrees of freedom,

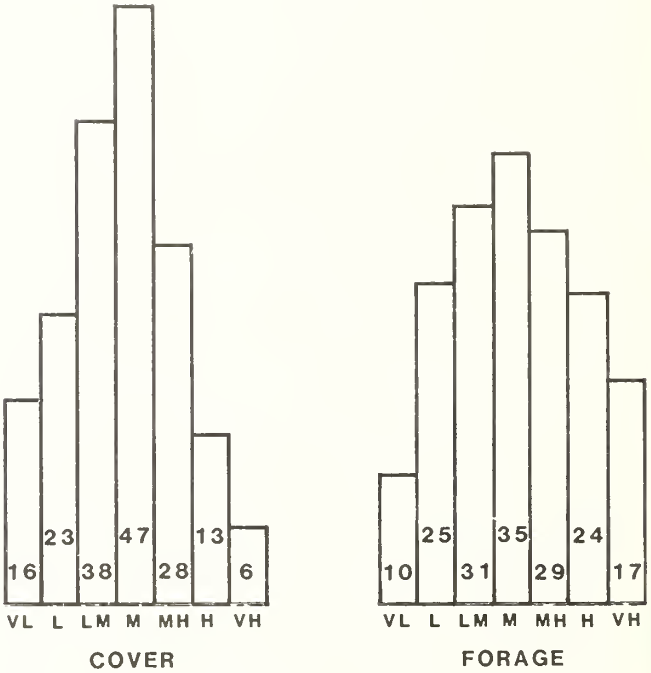

Figure 4.—Frequency distribution of 171 elk habitat settings, by final habitat quality ratings, for summer cover and forage.

Table 4.—One-factor analysis of variance showing the independent influence of six factors on elk summer cover and forage quality ratings

Source of variation	Degrees of freedom	Cover SS	Cover F	Cover α	Forage SS	Forage F	Forage α
Habitat type (HT)	17	1,215	31.4	<0.001	4,791	468.0	<0.001
Cover type (CT)	11	892	33.2	<0.001	2,766	149.3	<0.001
HT/CT	36	1,295	15.9	<0.001	4,809	223.1	<0.001
Tree size (TS)	3	663	86.5	<0.001	57	6.1	0.001
Stand density (SD)	3	2,260	442.4	<0.001	94	10.1	<0.001
TS/SD	5	2,727	374.6	<0.001	99	6.4	<0.001
Error				varies			
Total	1,880	5,457	—	—	5,913	—	—

sums of squares (SS), the F-statistic (F), and the statistical significance level (α) associated with each PSR component pertaining to cover or forage. Individually, all factors were highly significant. Inspection of sums of squares can indicate relative importance in accounting for variation in cover or forage ratings. The cover analysis indicates that structure of vegetation—TS, SD, TS/SD—is far more important to cover quality ratings than is type of vegetation—habitat type group (HT), cover type (CT), HT/CT. Of the two structure-oriented variables (TS and SD) the stand density variable (SD) is more significant, but tree size (TS) is also important. In contrast, the forage analysis shows that type of vegetation is more important to forage quality ratings than is structure. Furthermore, habitat type group (HT) alone is more important than cover type (CT) alone, explaining almost as much variation as the combination, HT/CT. But the problem with one-factor analyses is that they are incapable of assessing interaction of factors.

The second series of analyses were two-factor analyses of variance on cover and forage ratings. The data set needed to be reduced to 1,815 observations to achieve statistical balance. The two factors considered were the combinations of HT/CT and TS/SD. The purpose was to assess the role of the overall interaction between vegetation structure and vegetation type in habitat quality. Table 5 shows the results, reinforcing the importance of vegetation structure (TS/SD) for cover and vegetation type (HT/CT) for forage. But these analyses were performed to examine the interaction of vegetation structure and type. F-tests of the interaction between vegetation type and structure (A×B) were statistically significant for both cover and forage. However, that statistical significance clearly resulted from the enormous degrees of freedom in the error term. We judged the magnitude of the interaction effect, as indicated by sums of squares, to be trivial—too small for practical importance. We therefore elected to ignore interaction effects between structure (TS/SD) and type (HT/CT) of vegetation.

The third series of analyses were designed to assess the more restricted interaction of tree size (TS) or stand density (SD) with type of vegetation (HT/CT). The three-factor analysis of variance used again called for a reduction in the number of observations in order to achieve statistical balance. Table 6 contains the results. The pattern of statistically significant interaction terms is more pronounced in the cover than forage analysis. In fact, for forage, three of the four interaction terms were not statistically significant. The most substantial interaction found was between vegetation type (HT/CT) and tree size (TS) regarding cover ratings. Nevertheless, even for the significant terms, the magnitude of the interaction effects shown by their sums of squares was trivially small and overwhelmed by the main effects. Interaction effects were again ignored.

Table 5.—Two-factor analysis of variance showing the influence of HT/CT, TS/SD, and their interaction on elk summer cover and forage habitat quality ratings

Source of variation	Degrees of freedom	Cover SS	Cover F	Cover α	Forage SS	Forage F	Forage α
HT/CT (A)	32	1,069	43.8	<0.001	4,660	270.3	<0.001
TS/SD (B)	4	2,524	828.3	<0.001	62	128.8	<0.001
Interaction: A × B	128	298	3.1	<0.001	107	1.6	<0.001
Error	1,650	1,258	—	—	889	—	—
Total	1,814	5,150	—	—	5,718	—	—

Table 6.—Three-factor analysis of variance showing the influence of HT/CT, TS, SD, and their interactions on elk summer cover and forage quality ratings

Source of variation	Degrees of freedom	Cover SS	Cover F	Cover α	Forage SS	Forage F	Forage α
HT/CT (A)	32	759.0	29.6	<0.001	3,646.00	212.9	<0.001
TS (B)	1	439.0	547.0	<0.001	5.00	9.5	0.003
SD (C)	1	1,976.0	2,464.9	<0.001	54.00	100.9	<0.001
Interactions: A × B	32	107.0	134.0	<0.001	24.00	1.4	ns[1]
A × C	32	81.0	101.5	<0.001	40.00	2.3	<0.001
B × C	1	6.9	8.6	0.004	.04	.1	ns
A × B × C	32	50.6	63.1	<0.001	25.00	1.4	ns
Error	1,320	1,058.0	—	—	706.00	—	—
Total	1,451	4,479.0	—	—	4,500.00	—	—

[1] Statistically nonsignificant at 0.05 level.

Table 7.--Final analysis of variance showing influence of various factors and their interactions on elk summer cover and forage quality ratings

Source of variation	Degrees of freedom	Cover			Forage		
		SS	F	α	SS	F	α
Habitat type (HT)	17		not included		4,791	468.0	<0.001
Cover type (CT)	11		not included			not included	
HT/CT	36	1,295	15.9	<0.001		not included	
Tree size (TS)[1]	3	663	86.5	<0.001		not included	
Stand density (SD)[1]	3	2,260	753.5	<0.001	94	10.1	<0.001
TS/SD	5		not included			not included	
Interactions	varies		not included			not included	
Error	varies	1,239			1,028		
Total	1,881	5,457			5,913		

[1] Nonstocked was also considered a size and density class in these analyses.

Table 8.—Ranked effect of forest habitat type group/vegetation cover type combinations, tree size class, and stand density class on elk summer cover quality ratings, for final model[1]

Combinations				
Cover types	Habitat type groups	Contribution	Tree size class	Contribution
Subalpine fir	Subalpine fir I	1.6	Sawtimber	0.4
Western redcedar	Western redcedar/grand fir	1.6	Poletimber	.4
Engelmann spruce	Subalpine fir II	1.3	Seedling/sapling	-.7
Grand fir	Western redcedar/grand fir	1.2		
Lodgepole pine	Subalpine fir II	1.1		
Engelmann spruce	Subalpine fir IV	1.0	**Stand density class**	
Engelmann spruce	Spruce	.8		
Engelmann spruce	Subalpine fir II	.8	Well	1.1
Subalpine fir	Subalpine fir IV	.7	Medium	.4
Hardwoods	Spruce	.4	Poor	-1.3
Western larch	Subalpine fir I	.3		
Lodgepole pine	Subalpine fir I	.3		
Douglas-fir	Douglas-fir IV	.2		
Douglas-fir	Subalpine fir I	.2		
Ponderosa pine	Douglas-fir II	.2		
Hardwoods	Bottomlands	.2		
Lodgepole pine	Spruce	.1		
Subalpine fir	Subalpine fir III	0		
Douglas-fir	Douglas-fir II	0		
Lodgepole pine	Subalpine fir IV	-.1		
Lodgepole pine	Douglas-fir IV	.2		
Ponderosa pine	Douglas-fir III	-.3		
Lodgepole pine	Douglas-fir III	-.3		
Shrubs	Mountain brush[2]	-.3		
Douglas-fir	Douglas-fir III	-.3		
Whitebark pine	Subalpine fir III	-.4		
Lodgepole pine	Subalpine fir III	-.4		
Whitebark pine	Whitebark pine	-.6		
Douglas-fir	Douglas-fir V	-.6		
Ponderosa pine	Douglas-fir V	.7		
Douglas-fir	Douglas-fir I	-1.0		
Ponderosa pine	Douglas-fir I	-1.0		
Ponderosa pine	Ponderosa pine	-1.1		
Douglas-fir	Scree	-1.4		
Ponderosa pine	Scree	-1.7		
Forbs and grasses	Mountain meadow[2]	2.5		
Forbs and grasses	Mountain grassland[2]	-2.5		

[1] Overall mean habitat rating = 3.6.

[2] Tree size class and stand density class contributions are not applicable.

Final judgments on the importance of various factors and their interactions were based on the knowledge gained in the one-factor, two-factor, and three-factor analyses. Statistical significance and simplicity were important considerations. A simpler model was selected over a more complex one if both were roughly equivalent in helping understand habitat quality. For example, while interaction terms were frequently found significant, their contribution to understanding habitat quality was small, but their addition to complexity was great. The three-factor model, without interactions, was selected as the best model for understanding summer cover quality. Summary analysis of variance results (table 7) shows that the sums of squares for stand density are clearly the most influential factor in explaining cover quality ratings, followed by the combination of habitat type group with cover type, and finally, tree size class. These factors account for 77.3 percent of the variation in cover quality. A two-factor model, consisting only of habitat type groups and stand density, was selected for understanding forage quality. In forage analyses containing interaction terms, the interactions were either statistically insignificant or so small they could be ignored. Furthermore, almost all variation explained by the combination TS/SD was accounted for by SD alone. Similarly, HT accounted for nearly all of the variation explained by the combination of HT/CT. Table 7 also displays analysis of variance results for forage. The factors shown accounted for 82.6 percent of the variation in forage quality ratings.

The cover model in table 7 can be presented in equation form as a three-factor statistical model without interaction terms:

$$C_{ijk} = \mu + (HT/CT)_i + TS_j + SD_k$$

This equation is interpreted as follows: the cover quality (C) of a specific elk habitat setting (ijk) is equal to the overall cover mean (μ), plus the contribution associated with its specific combination (i) of habitat type group and cover type (HT/CT), plus the contribution of its specific (j) tree size class (TS), plus the contribution of its specific (k) stand density class (SD). The overall cover mean (μ) for all elk habitat settings is 3.6. Table 8 shows the contributions associated with levels of all factors. Both the sign and magnitude of the contributions are meaningful. Consider the sign: if the sign of the contribution is positive, the cover value is greater than the overall mean; if negative, it is less. The first 17 combinations of HT/CT have positive contributions, the remainder are zero or have negative signs. Similarly, two levels of the tree size and stand density are positive, the other is negative. Poorly stocked stands or seedling-sapling trees tend to force the overall rating below the mean. The magnitude of the contributions is also important. The larger the contribution, the greater the effect, positive or negative. A contribution of 1.0 will have twice the effect on cover quality as will a value of 0.5. A well-stocked stand will tend to be rated at least two classes higher (1.1 + 1.3) than an identical situation, but under poor stocking.

The forage model reflected in table 7 can also be expressed as a two-factor statistical model without interaction terms:

$$F_{ij} = \mu + HT_i + SD_j$$

Here, the forage value (F) of a specific elk habitat setting (ij) is equal to the overall forage mean (μ), plus the contribution of a specific (i) habitat type group (HT), plus the contribution of a specific (j) stand density (SD) class. Table 9 contains these contributions. The overall forage mean is 4.1. All interpretations regarding sign and magnitude of contributions pertaining to forage are the same as discussed previously for cover.

Table 9.—Ranked effects of forest habitat type groups and stand density class on elk summer forage quality ratings, for final model[1]

Habitat type groups	Contribution	Stand density class	Contribution
Mountain meadow[2]	2.9	Poor	0.2
Spruce	2.4	Medium	.1
Subalpine fir I	2.2	Well	−.2
Western redcedar/grand fir	1.3		
Subalpine fir II	1.1		
Subalpine fir IV	.5		
Mountain grassland[2]	.4		
Mountain brush[2]	.3		
Bottomland	.1		
Douglas-fir IV	−.2		
Douglas-fir III	−.6		
Whitebark pine	−.6		
Douglas-fir II	−1.0		
Subalpine fir III	−1.0		
Douglas-fir V	−1.7		
Ponderosa pine	−1.9		
Douglas-fir I	−2.0		
Scree	−3.1		

[1] Overall mean habitat rating = 4.1.

[2] Stand density class contributions are not applicable.

Habitat Type Components.—For some purposes, assessing elk habitat quality in terms of vegetation type and structure may be adequate. For other purposes it is desirable to better understand why habitat quality varies. In this regard, the concept of forest habitat type is a key consideration because it is a composite of several environmental factors. In short, while habitat type per se is a taxonomic structure, it consists of environmental factors that actually cause variation in habitat quality.

The study team identified six major components of forest habitat type: type of understory vegetation, density of understory vegetation, elevation, topographic setting, moisture, and temperature. Each component was subdivided. For example, temperature was divided into hot, warm, moderate, and cool. Each of the 171 elk habitat settings was coded according to these components and subdivisions. A series of analyses were conducted to determine if the categories identified were statistically distinguishable from each other in terms of habitat quality ratings. Frequently they were not. When insignificant differences were detected, subdivisions were recombined into the following divisions:

Component	**Divisions**
Understory type	Primarily grasses (UT1)
	Primarily shrubs (UT2)
Understory density	Sparse or moderate (UD1)
	Dense or varied (UD2)
Elevation	Low or middle (E1)
	High or all (E2)
Topograpic setting	South or west face (TS1)
	All faces (TS2)
	Bottomland or benches (TS3)
Moisture	Dry or moderately dry (M1)
	Moderate or wet (M2)
Temperature	Hot or warm (T1)
	Moderate or cool (T2)

Figure 5 shows the percentage distribution of habitat quality ratings over all habitat type components and their associated divisions, for both cover and forage. For

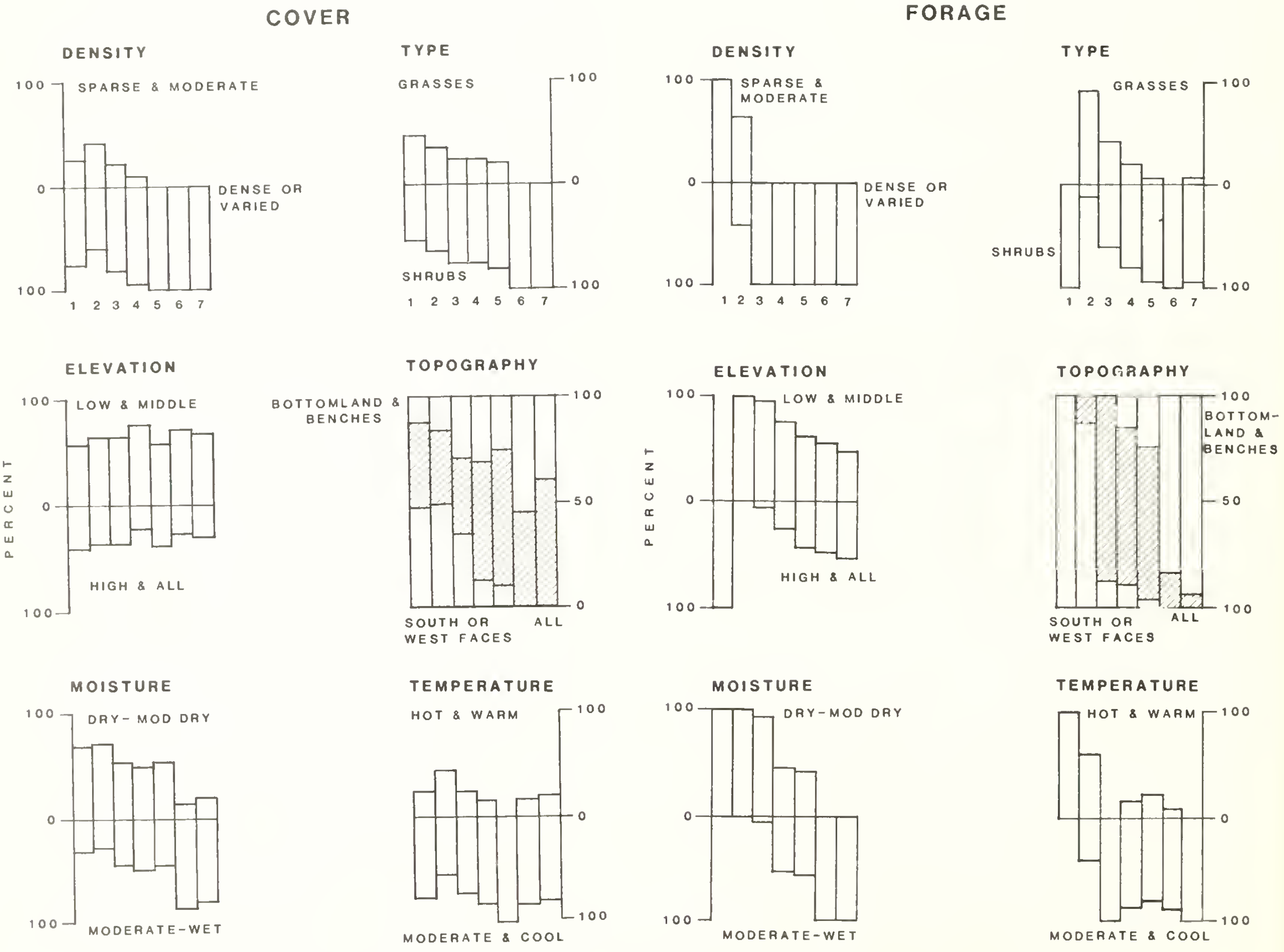

Figure 5.—Percentage distribution of 171 elk habitat settings, by final habitat quality ratings, for components of forest habitat type, summer cover, and forage.

these components to be useful in understanding elk habitat quality, trends should be present. Perhaps the most obvious trend pertains to site moisture and forage quality ratings. There, 100 percent of the PSR's rated very low or low (1 or 2) were from dry or moderately dry sites; conversely, 100 percent of the PSR's rated high or very high (6 or 7) were from moderate or wet sites.

A series of one-factor analyses were conducted to determine which single component of forest habitat type had the greatest effect on cover and forage quality. Table 10 shows these analyses. Because most components were highly significant, attention was focused on the sums of squares for further interpretation. Not surprisingly, habitat type components had little influence on cover quality ratings, the largest sums of squares accounting for only 61 of the 378 total. The same relationship was shown earlier in table 4 where the habitat type factor (not the components) was shown to be strongly related to forage but not to cover quality. Further examination revealed that the most important components for cover were topographic setting, density of understory vegetation, and moisture. The most important components for forage were topographic setting, moisture, and density of understory vegetation.

Subsequent analysis of habitat type components was thwarted for two reasons. First, because these components were not the primary independent variables used in this study, they played no role in the basic experimental design. When the set of elk habitat settings was selected to approximate a balanced experimental design, habitat type components were not considered as part of the balance. Consequently, multiple linear regression analysis was appropriate for use.[1] Second, habitat type components are not independent of each other. For example, wetter sites tend to be cooler sites and drier sites tend to be warmer sites. Because of the problem of nonindependence between components, regression results should be interpreted as indicative, not conclusive. The results are useful only in accounting for variation in habitat quality ratings, not in understanding the underlying biological causes and effects.

A multiple linear regression model was developed for both cover and forage quality. The levels associated with habitat type components were handled as "dummy variables." Table 11 shows the results of these analyses. For the forage model, 87 percent of the total variation in habitat quality ratings was explained by the six statistically significant habitat type components. Only about 19 percent of the total variation in cover ratings was explained by the two statistically significant components. This is not surprising because we have already

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[1] When an analysis involves an unequal number of observations in a subclass, routine analysis of variance techniques cannot be used to determine the influence of various factors on a dependent variable. In such cases, multiple linear regression techniques must be used (Draper and Smith 1981).

Table 10.—One-factor analysis of variance showing the independent influence of six habitat type components on elk summer cover and forage quality ratings

Source of variation	Degrees of freedom	Cover			Forage		
		SS	F	α	SS	F	α
Understory density	1	43.6	22.1	<0.001	172.7	104.2	<0.001
Understory type	1	31.1	15.1	<0.001	88.2	40.9	<0.001
Elevation	1	1.8	.8	ns[1]	10.9	4.2	.039
Topographic setting	2	61.2	16.2	<0.001	327.3	219.4	<0.001
Moisture	1	37.5	18.6	<0.001	251.9	212.1	<0.001
Temperature	1	12.4	5.7	.017	83.1	38.0	<0.001
Error				varies			
Total	170	377.8	—	—	452.6	—	—

[1] Statistically nonsignificant at 0.05 level.

Table 11.—Linear regression models and analysis of variance showing the influence of several independent factors (habitat type components) on elk summer cover and forage quality ratings

MODEL:

Cover: $C = 4.18 - 1.11(TS1) - 0.576(M1)$

Forage: $F = 6.5 - 1.35(M1) - 2.8(TS1) - 1.3(TS2) - 0.87(T1) - 0.62(E1) + 0.72(UT1)$

ANOVA:

Source	df	SS	F	α	df	SS	F	α
Regression	2	70.2	19.2	<0.001	6	394.4	185.1	<0.001
Error	168	307.6	—	—	164	58.2	—	—
Total	170	377.8	—	—	170	452.6	—	—
		$R^2 = 0.19$				$R^2 = 0.87$		

shown cover to be closely associated with stand structure rather than habitat type. In both models, the topographic setting and moisture were statistically significant variables. Additionally, temperature, elevation, and the type of understory vegetation were statistically significant in the forage model.

Table 12 shows the effect of the statistically significant independent variables on cover or forage quality rating. The component levels shown with "+" indicate that when that level is present, it tends to increase the overall habitat quality rating; a "−" means the rating tends to be decreased. The statistically nonsignificant (nss) component levels mean that their effect on habitat quality is so variable (erratic) that no additional systematic positive or negative effect on habitat quality could be discerned, given the presence of the statistically significant variables already in the model. Consider forage quality. Sites consisting primarily of a grass understory have a statistically significant higher quality than those consisting primarily of shrubs. Similarly, understory density does not have a statistically significant effect on forage quality after moisture, temperature, and other habitat type components have been used to explain rating variability.

Classification Functions.—One of the most desired outcomes of our study was the development of a field-oriented tool to predict habitat quality. The typical tool for this purpose would be a multiple linear regression model. But a regression model requires the dependent variable, habitat quality, to be measured on an interval or ratio scale. Our habitat quality ratings were measured on an ordinal scale. However, another tool, discriminant analysis, was appropriate.

In discriminant analysis, the objective is to assign or classify a subject into one or more groups (the dependent variable), based on measurements taken on a set of independent variables. In our case, the "subject" corresponds to elk habitat settings and the "groups" correspond to the seven habitat quality classes. A typical discriminant analysis develops linear classification functions, one for each group associated with the dependent variable (seven in our case). The subject is then classified into the group based on the highest classification function score. The approach we took was to develop a sequential analysis procedure resembling a dichotomous key used in taxonomy.

Two general classes of independent variables were used: habitat type components (elevation, moisture, and so forth) and combinations of tree size class and stand density class (TS/SD). Habitat type component codes and groupings are the same as before. The combinations of TS/SD are coded as follows:

C1 — Seedling and sapling, poorly stocked
C2 — Seedling and sapling, well stocked
C3 — Medium stocked, poletimber
C4 — Sawtimber, poorly stocked
C5 — Sawtimber, well stocked
C6 — Nonstocked.

The sequential discriminant analysis allows a user to apply a procedure that systematically interprets an elk habitat setting until the "most likely" habitat quality rating has been assigned. Figure 6 displays this sequential procedure in the form of a dichotomous key. Its use can be illustrated with an elk habitat setting with the following characteristics: UT1, UD1, E1, TS1, M1, T1, and C4. All variables are binary (zero or one) and should be interpreted as discussed with previous regression analyses. If the description for the variable is present, the variable takes on a value of one; otherwise the value is zero.[2] Using the equation associated with the first

Table 12.—Effect of habitat type components on elk summer cover and forage quality ratings

Component level		Cover	Forage
Understory type (UT)	— Primarily grasses	nss[1]	+
	— Primarily shrubs	nss	−
Understory density (UD)	— Sparse or moderate	nss	nss
	— Dense or varied	nss	nss
Elevation (E)	— Low or middle	nss	−
	— High or all	nss	+
Topographic setting (TS)	— South or west face	−	−
	— All faces	nss	
	— Bottomland or benches	nss	+
Moisture (M)	— Dry or moderately dry	−	−
	— Moderate or wet	+	+
Temperature (T)	— Hot or warm	nss	−
	— Moderate or cool	nss	+

[1] Not statistically significant at 0.05 level.

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[2] As with other statistical analysis procedures, discriminant analysis typically rests on a set of underlying assumptions. Perhaps the most critical is that of multivariate normality of the independent variable (Kleinbaum and Kupper 1978). Our analyses violate this assumption because all independent variables are discrete, handled as binary, dummy variables. This violation precludes rigorous statistical interpretation of the discriminant functions. It also means that the functions developed may not be optimal (Goldstein and Dillon 1978). However, our use of the functions is solely for classification purposes, and we make no claim regarding optimality.

If: $-4.20 + 8.07(C1) + 1.95(TS1) - 1.51(E1) + 2.22(UT1) - 1.59(UD1) > 0$ → Very low
↓
otherwise

If: $-5.70 + 3.55(C4) + 1.02(C3) - 9.86(C1) + 0.82(M1) + 1.82(TS1) + 3.63(UD1) > 0$ → Low
↓
otherwise

If: $-2.71 - 1.50(C5) + 5.96(C4) + 7.99(C1) + 4.20(TS1) - 0.73(E1) + 2.34(UD1) > 0$ → Low medium
↓
otherwise

If: $-6.27 + 10.36(C4) + 6.57(C3) + 7.35(C2) + 11.11(C1) + 2.81(M1) - 2.22(TS2) + 2.09(E1) + 4.25(UD1) > 0$ → Medium
↓
otherwise

If: $-0.44 - 1.55(C5) + 3.32(C2) - 1.74(T1) + 2.82(M1) + 4.02(TS1) > 0$ → High medium
↓
otherwise

If: $2.73 - 2.10(C5) - 1.24(T1) + 1.21(M1) - 1.92(TS2) > 0$ → High
↓
otherwise
↓
Very high

Cover

If: $-11.14 + 3.86(M1) + 4.81(TS1) - 3.58(E1) - 10.85(UT1) + 14.80(UD1) > 0$ → Very low
↓
otherwise

If: $-12.73 + 1.10(C2) - 2.09(T1) + 4.23(M1) - 3.20(TS2) + 8.26(TS1) + 3.60(E1) + 14.66(UD1) > 0$ → Low
↓
otherwise

If: $-7.02 + 1.89(C5) + 1.04(C3) + 2.01(C2) - 2.58(T1) + 5.97(M1) - 1.56(TS2) + 2.95(TS1) + 4.25(E1) > 0$ → Low medium
↓
otherwise

If: $-3.36 + 1.79(E1) + 5.74(TS1) + 1.98(TS2) + 1.75(M1) + 1.53(T1) > 0$ → Medium
↓
otherwise

If: $-6.11 - 11.15(UT1) + 20.54(TS1) + 10.25(TS2) + 4.41(M1) + 10.38(T1) + 1.79(C2) - 1.42(C3) - 2.78(C4) > 0$ → High medium
↓
otherwise

If: $1.71 - 15.49(UT1) - 1.67(E1) + 10.78(TS2) + 10.78(T1) + 8.30(C2) - 3.29(C4) + 8.18(C5) > 0$ → High
↓
otherwise
↓
Very high

Forage

Figure 6.—Seven-class dichotomous key for discriminant analysis of elk summer cover and forage quality.

branch of the cover dichotomous key, calculate the score:

$$VL = -4.20 + 8.07(0) + 1.95(1) - 1.51(1) + 2.22(1) - 1.59(1)$$
$$= -3.13$$

Following the instructions, the magnitude of the score (less than zero) indicates that this elk habitat setting is "otherwise," not "very low," and that computations should continue. The score for the second-step equation is +4.12. Because this score exceeds zero, the site would be assigned a "low" habitat quality rating.

The reliability of a discriminant analysis is indicated by its ability to correctly classify subjects—elk habitat settings. Overall, the sequential discriminant function procedure correctly classified 60 percent of the cover ratings and 67 percent of the forage ratings. Most misclassifications occurred within a more general rating, within the lows, mediums, and highs. For example, while the procedure had difficulty distinguishing between high and very high, it correctly classified all of the "high" quality sites. We repeated the sequential analysis using three habitat quality classes (low = very low and low; medium = low medium, medium, and high medium; high = high and very high). This approach correctly classified 84 percent of the sites for cover and 92 percent for forage. The dichotomous key for the three-habitat quality class analysis is shown in appendix C.

Delphi Process

Although the Delphi process is rather straightforward, there are several major decisions that must be made and can affect results. This section evaluates a wide range of study results pertaining to four major aspects of Delphi: (1) selection and number of participants, (2) consensus achieved and what affected it, (3) the data-gathering instrument or questionnaire used, and (4) time considerations such as how long parts of the Delphi process took.

Participant Selection and Number.—The participant identification process began with the "starter" identifying eight persons as experts in elk habitat for western Montana. If any of several other ways of identifying experts had been used the number of choices would have changed:

Selection method	Number of experts identified
Starter only	8
Any one identifier	2—19
All identifiers combined	30
Top-one method	2
Top-two method	5
Top-three method	13
Top-four method	15

Some 30 experts were identified by all persons contacted. If any one person had been contacted as our sole source of "expert" names, as few as two or as many as 19 persons would have been identified as expert. The number of experts identified by the "top" method quickly increases as the top-three method is approached and then levels off. We suspect that if a top-five method had been used, results would have been essentially the same as the top-four method.

A wide difference exists between individuals in their personal perception of who is an expert. That is why the top-three format identified 13 individuals, not three. Comparing individuals contacted, perceptions ranged from total agreement to total disagreement as to which persons constitute the top three experts. There was much more consistency in identifying experts in the top-one or top-two formats. Figure 7 illustrates a typical pattern in group dynamics, focusing on five individuals being identified as in the top-two format: the starter identified A and B; when contacted, A and B identified two new top-two experts (C and D); when C and D were contacted, only one new expert (E) was identified; when contacted, E identified two previously identified persons.

The participant selection method should be related to the number of participants desired. If a small number of participants is adequate, the top-one or top-two method might be appropriate. If a larger number is desired, the top-three, top-four, or all combined methods might have to be used. This study used all approaches because we had no idea how many experts would be identified by each method. We wanted a large group so that we could later simulate the outcome of using a smaller number of participants. Once the results were known, we selected the 13 experts identified by the top-three method to serve as participants in our Delphi project.

Is the process of identifying elk habitat experts affected by the occupational status, degree of expertise, or the amount of professional elk habitat experience on the part of those persons doing the identifying? To address this issue, each of the 13 experts was assigned a code reflecting occupational status, expertise, and experience. Experts were assigned to an occupational

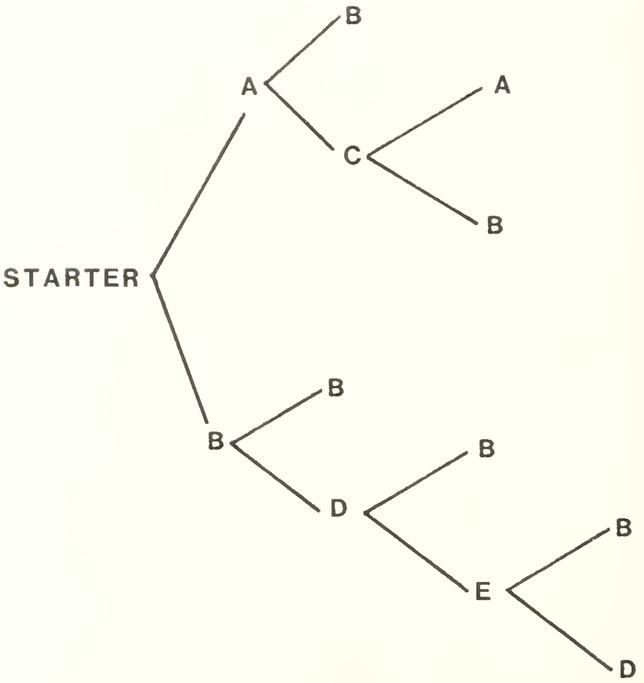

Figure 7.—Illustration of networking associated with a top-two procedure of expert identification.

category based on their current job—either managers/administrators or researchers/academics. Each expert was assigned to the upper or lower half of the expertise listing, based on the frequency of being identified as an expert. For example, based on the pattern of identification shown in figure 7, "B" (named six times) would be assigned to the upper half and "E" (named once) to the lower half. A measure reflecting experience was developed. Each expert's professional career was converted to an expression of "annual equivalents" of elk habitat experience. For example, 10 years of involvement at a 50 percent level of commitment was expressed as 5 years (or annual equivalents) of experience.

Does the occupation, expertise, or experience of an identifier affect the number of persons identified as experts? No. A series of one-factor analyses assessed whether, for example, the average total number of experts identified by managers/administrators (M/A) was significantly different from the average identified by researchers/academics (R/A). Table 13 shows that, overall, each person identified an average of 7.1 experts and that the M/A average was not significantly different from the R/A average. Similarly, simple linear regression analysis showed that the years of experience had no statistically significant effect on the total number of experts identified. In fact, we found no evidence that occupation, expertise, or experience had any effect on the number of experts identified.

Was there an occupational bias in the type of expert identified? That is, do identifiers from one occupational status tend to identify only others from that status as experts? Again no. A chi-square test of independence between occupational status of identifier and occupational status of the identified experts failed to detect a statistical dependency. The identifiers were not occupationally biased in their judgments.

Although the top-three method identified 13 experts, only 11 actually participated throughout the study. Two declined participation in the study for reasons unrelated to elk habitat quality ratings. The 11 who participated were distributed between occupational status and expertise levels as follows:

	Occupation status	
Level of expertise	M/A	R/A
Upper half	2	4
Lower half	4	1
	6	5

After all elk habitat ratings had been obtained, the question arose: Are the ratings related to the professional status of the participants? A series of one-factor analyses of variance were conducted. The dependent variable consisted of the final summer cover and forage quality ratings. As before, the independent factors of expertise and occupation were handled as having two levels each: M/A and R/A for occupation and upper and lower half for expertise. Experience was also treated as a factor, but with three levels. Because participants were divided almost evenly into three experience classes, we labeled the classes as most, least, and middle. Table 14 shows the resulting analyses of variance. Two points warrant mention. First, except for the experience factor in the forage analysis, all other factors were always statistically significant. That is, statistical evidence

Table 13.—Comparison of average number of experts identified per identifier, by method, occupation, expertise, and experience

Selection method	Overall average number of experts	Occupation		Expertise		Years of experience
		M/A	R/A	Lower	Upper	
Total	7.1	-- nsd --[1]		-- nsd --		nss[2]
Top-one	1.6	-- nsd --		-- nsd --		nss
Top-two	2.9	-- nsd --		-- nsd --		nss
Top-three	5.0	-- nsd --		-- nsd --		nss
Top-four	5.3	-- nsd --		-- nsd --		nss

[1] Not statistically different at 0.05 level.
[2] Not statistically significant at 0.05 level.

Table 14.—One-factor analysis of variance showing the independent influence of three participant characteristics on elk summer cover and forage quality ratings

Source of variation	Degrees of freedom	Cover			Forage		
		SS	F	α	SS	F	α
Experience	2	19.0	3.3	0.036	15.3	2.4	ns[1]
Expertise	1	128.9	45.5	<0.001	48.7	15.6	<0.001
Occupation	1	61.1	21.3	<0.001	41.0	13.1	<0.001
Error	---------- varies ----------						
Total	1,880	5,457.0	—	—	5,913.0	—	—

[1] Statistically nonsignificant at 0.05 level.

exists that habitat quality ratings varied with professional characteristics of the participating expert. Second, the effects of these factors were extremely small. Were it not for our desire to assess the implications of the effect professional status has on ratings, further analyses of professional status would have been discontinued. Instead, only the effect of the experience factor was judged to be so small that it would not be considered further.

To provide a direct comparison between the effect of professional status and vegetation characteristics on habitat quality ratings, a series of three-factor analyses were conducted. Expertise or occupation was treated (separately) as one factor, and combination of habitat type groups and cover types (HT/CT), along with combination tree size and stand density classes (TS/SD), constituted the other two factors. Analyses of variance indicated that the occupation or expertise factors are statistically significant. However, the effect was small. Whereas the factors pertaining to vegetation type and structure accounted for 70 to 80 percent of the variation in habitat quality ratings, professional status accounted for 2 percent or less. Nevertheless, cover and forage ratings do vary (at a statistically significant level), depending on the participant's occupational status or level of expertise. How much and in what way were they different? Based on subsequent investigations, the listing below provides some indication of these differences:

	Cover	Forage
Researchers/academics compared to managers/administrators	+0.4	+0.3
More expertise compared to less expertise	+.5	+.3

On the average, R/A systematically rate elk habitat higher than do M/A. Similarly, the more expert participants rate habitat higher than the less expert. The magnitude of these effects should be interpreted both in the context of the seven-level rating scale and overall rating means, 3.6 for cover and 4.1 for forage Whether differences of these magnitudes are of practical significance is judgment that lies beyond the purview of this report. This much can be said: if only the less expert or only R/A had been selected as participants, resulting habitat ratings would have been systematically different. Caution: because there is a high correlation between the occupational and expertise classes, the differences shown above are not additive.

How many participants are needed for a Delphi experiment? That depends on a number of factors, particularly the cost of participation, importance of the results, and the inherent variability of the topic. A relatively large number of experts was selected to participate in this study so that the effect of smaller groups could be assessed.

One critical assumption must be made in comparing alternative numbers of participants: the nature of the feedback would not be affected by the number of participants. This assumption permitted us to neutralize the effect of feedback and simulate results if fewer than 11 experts had participated. To do this, results obtained after the third iteration with 11 participants (the assumed standard) were compared to results that would have been obtained with a lesser number of participants. The third iteration median involving the 11 experts amounts to consensual "truth" within the context of this Delphi application. First iteration results for each expert were individually compared to that standard when prospects of a single participant were evaluated.

Figure 8 shows a comparison between the third iteration standard and the range of results that could have occurred with different numbers of participants. For example, with two participants, the results could have ranged from an average deviation of more than 1.0, about 75 percent above the standard, to as little as 0.2, nearly 50 percent below the standard. If seven or more participants were used, the results would have been within 25 percent of the standard. Not all subsets of participants necessarily differ from the total 11. Indeed, there are specific groups of two, four, six, and more participants that could have been used such that their median ratings would have been virtually identical to those of the 11. However, the problem is that no *a priori* basis exists to select the "correct" individuals for any subset.

These comparisons tend to mask the great differences in study results that could have been obtained if fewer participants had been used. To illustrate, consider the extreme case of one participant. Figure 8 shows that if only one participant were used, that person's response could have been as much as 130 percent of the standard. Depending on which of the 11 individuals was asked to assess the forage quality of the mountain grassland situation, response would have ranged from "very low" to "very high" quality, the maximum possible range. While ranges for other situations were not necessarily that

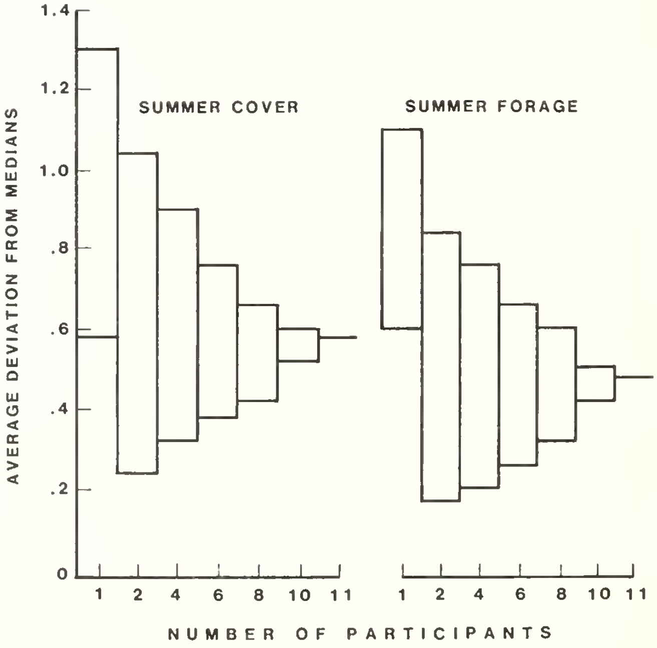

Figure 8.—Range of deviations from final consensus for elk summer cover and forage quality ratings, by alternative number of participants.

large, they were typically large enough to cast doubt on the wisdom of relying on a single individual's assessment.

The study team had expected large differences between the standard and small number of participants, but that as the number of participants increased, ratings would converge to the third iteration, 11-participant standard. Instead, the convergence pattern shown in figure 8 is nearly linear. Based on our research, we conclude that more participants are better than less, at least up to 11.

Effects on Consensus.—The ultimate objective in any Delphi application is to achieve or promote consensus among participants regarding some topic. While the word consensus has an intuitive meaning (general agreement), it has no direct quantitative interpretation. As discussed earlier, the quantitative measure of consensus we developed for each elk habitat setting (PSR) was the mean deviation from the median. Iteration, participant characteristics, number of participants, and more, will be discussed, all regarding their effect on consensus.

As the study progressed from the first to the third iteration, there was convergence toward consensus, but overall habitat quality ratings did not change. Table 15 shows that the overall average of the medians did not change with iteration. The same is also true for individual PSR's. With each iteration there were 171 opportunities for median ratings to change. In fact, only seven cover medians changed between the first and second iterations and only four changed between the second and third. Forage medians changed even less: five between the first and second and two between the second and third. In no case did any median change by more than one class. Basically, the first iteration provided a near-perfect approximation of the final results. If the purpose of the Delphi exercise were simply to determine median habitat quality ratings, one iteration would have been adequate.

But Delphi projects not only attempt to assess some topic, they also strive to promote consensus among participants. Consensus enhances credibility. The second point shown in table 15 is the consistent pattern of improvement in consensus for both summer cover and forage. The overall average deviation from the individual medians after the first iteration was about 0.8 of a class. This reduced by about a third between the first and second iterations, a statistically significant improvement in consensus. Average deviation from the medians dropped again, by about 15 percent, between the second and third iterations—once more a statistically significant change. Changes between the first and second iterations accounted for over three-fourths of the total convergence toward consensus. We strongly suspect that if a fourth iteration took place, virtually no additional improvement in our measure of consensus would have occurred. The fact that both the ultimate level of consensus and consensus improvement for forage were better than cover surprised us. Communication with participants specifically indicated that they were having much more difficulty with forage ratings than cover.

The pattern of group movement toward consensus resulted from individual response changes by each participant. The range of differences between individual participants and the group norm was substantial. Consider the case of first iteration cover, the largest range. While the overall group average deviation from the medians was 0.82, individual average deviations from the group norm ranged from as low as 0.50 to as high as 1.29, more than a twofold difference. By the third iteration the range had decreased considerably, to a low of 0.07 and a high of 1.05. Similar patterns can be noted for forage. The lowest individual average deviation from the medians was 0.07, for third iteration cover. That person's ratings and the group's median cover ratings agreed for 158 of the 171 elk habitat settings, and none of the 13 differences were ever by more than one class.

As each participant was given the opportunity to adjust ratings, the ratings were generally adjusted toward the group norm. The largest individual movement toward group consensus occurred between the first and second iterations where the differences between one participant's judgment and the overall medians were reduced by 64.7 percent, almost two-thirds. But more interestingly, some participants diverged from the overall medians. The largest divergence occurred between the second and third iterations for cover where the difference between one of the participants and the group norm increased by more than 35 percent. Therefore, the overall pattern of group convergence is a real mixture of individual participants converging toward and diverging from the group norm.

We conducted several statistical analyses on the effect of participant characteristics on consensus. All analyses treated the third iteration mean deviation from the medians as the dependent variable. Categories for the independent factors of occupational status, expertise

Table 15.—Average median and mean deviation from medians for elk summer cover and forage quality ratings, by Delphi iteration

Characteristic	Iteration	Cover	Forage
Average median	1	[1]3.61 ⎤	4.07 ⎤
	2	3.62 ⎥	4.09 ⎥
	3	3.63 ⎦	4.10 ⎦
Mean deviation from medians	1	.82	.80
	2	.60	.50
	3	.52	.42

[1] Brackets denote no statistical difference at 0.05 level.

level, and experience were as before. Two additional independent factors were added—confidence and time. One of the questions asked in the exit interview questionnaire dealt with how confident participants were with cover and forage results. Responses were handled as categories such as "very confident," "confident," and so forth. The study team also had records on how much time participants devoted to their assigned Delphi tasks. Time was handled as continuous variables in simple linear regression analyses.

Analysis results shown in table 16 indicate that the level of consensus achieved for each participant was not related to the participant's occupation, expertise, experience, or the confidence each had in study results. In terms of consensus, managers/administrators did not differ from researchers/academics by a statistically significant amount. Participants expressing more confidence in study results did not differ from those expressing less. These results tend to confirm an advantage ascribed to Delphi—it overcomes participant status influence. Status can be based on occupation, expertise, or experience. However, movement toward consensus was significantly related to the amount of time devoted to Delphi tasks. Highly significant regression models explained about 55 percent of this variation in consensus, simply on the basis of time. Our study results indicated that movement toward consensus was related to what the participants did, not who they were.

The magnitude of measured consensus is intimately tied to the measurement scale, a seven-level scale in this study. As the number of levels on the measurement scale increases, so do the opportunities for choice or disagreements. Hence, one would expect more consensus with fewer scale levels than with more. To assess the effect of measurement scale change on consensus, an analytical measure was needed that could simultaneously reflect both changes in rating variability and changes in rating scale. The coefficient of variation (CV), expressed as a percentage, is such a measure:

$$\%CV = \frac{s}{\bar{X}}\, 100$$

where "s" denotes standard deviation and "$\bar{X}$" the mean. Whereas mean deviation from the median (MDM) is an absolute measure of consensus, %CV is a relative measure, allowing comparisons between different configurations of the rating scale.

Table 16.—One-factor analysis of variance results showing extent to which consensus (mean deviation from medians) varies with five independent participant characteristics

Independent participant characteristic	Cover	Forage
Occupation	No	No
Expertise	No	No
Experience	No	No
Confidence in results	No	No
Time devoted	Yes	Yes

Different rating scale configurations amount to different arrangements of the grouping or sorting process. Because the participants were instructed to follow a specific procedure, habitat ratings could be rearranged to simulate four sorting outcomes—the original seven-level scale (D), two five-level scales (B and C), and a three-level scale (A), as shown in figure 9.

Habitat ratings were recoded, as appropriate, to simulate the three new grouping arrangements. Original and recoded ratings were used to compute %CV for each of the 171 PSR's. A two-factor analysis of variance was conducted where %CV was the dependent variable, and the four grouping arrangements along with the three iterations constituted levels of the two independent factors. The data sets contained 2,052 observations (171 PSR's × 3 iterations × 4 grouping arrangements). Analysis results indicate that the iteration means and grouping means were significantly different while their interaction was not. The result pertaining to iterations was expected because statistically significant movement toward consensus with increased iterations has already been demonstrated and discussed. The fact that statistically significant differences were found between grouping means, but that the interaction between grouping and iteration was not significant, signifies that the differences in group means did not depend on iteration. The differences were present in all iterations.

Based on the analysis of variance just discussed, the listing below provides insight into the consequences of alternative grouping arrangements:

Grouping arrangement	%CV Cover	%CV Forage
A	28	21
B	23	16
C	28	26
D	21	19

The lower the %CV, the smaller the relative variation. Brackets indicate nonsignificant differences. Note first that not all %CV for various groupings are significantly different from each other. Most surprisingly, the forage %CV for grouping A and grouping D are not statistically different. That means that relative consensus would not have been increased if the participants sorted into three-class scale consisting of low, medium, and high habitat quality classes rather than into the seven classes that were actually used. However, a marked statistical increase should be noted for cover rating. The %CV value of 28 percent was reduced to about 21 percent with movement from grouping A to grouping D. This degree of increase toward consensus associated with different grouping arrangements is roughly equivalent to the increase observed when going from the first to the third iteration. Substantial increases toward consensus are apparently possible by the use of a scale with fewer classes, but the possible increases may not actually take place. We know of no way to distinguish beforehand between situations where increases toward consensus would take place (as for cover) and situations where consensus either is not increased or is actually decreased (as for forage, especially grouping C).

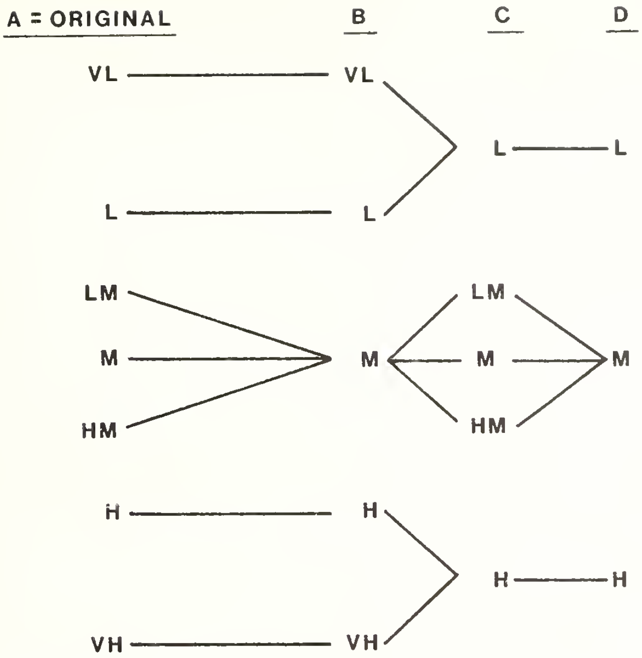

Figure 9.—Four alternative grouping arrangements.

Table 17.—Percentage distribution of adequacy judgments for pictorial site representation (PSR) components and component combinations, by elk summer cover and forage

Component and combination	Percent adequacy	
	Cover	Forage
Single component		
Photo (P)	27.3	18.2
Sketch (S)	54.6	45.5
Narrative (N)	63.6	72.7
Two components		
P and S	27.3	18.2
P and N	36.4	63.6
S and N	81.8	63.6
Three components	81.8	81.8

Data-Gathering Instrument and Feedback.—There were several unique ways by which the Delphi process was implemented in this study. The data-gathering instrument was one. It consisted mainly of pictorial site representations (PSR's) and the Q-sort process. Additionally, the method of providing feedback was somewhat unique. This section presents our findings on these topics. The basis for our findings was the exit interview questionnaire administered after all habitat quality ratings had been obtained.

The first thing participants dealt with was the set of 171 PSR's representing a variety of elk habitat settings. Each PSR consisted of three parts—a photocopy of a color photograph depicting the setting, a sketch illustrating a cross-sectional view of the vegetation, and a written narrative description of the setting. We asked the participants how adequate these components were as a basis for rendering judgment on habitat quality. Table 17 shows the percent adequacy associated with various combinations of the three components with respect to cover and forage. First, the vast majority of participants felt that together all three components were adequate to accomplish the needed tasks. Second, the photocopy was consistently judged to be inferior to either the sketch or the narrative. While the combination of the sketch and narrative was highly adequate for both cover and forage ratings, the narrative was clearly more useful. In the case of forage, the narrative alone was almost as adequate as it was in combination with any other component. On the other hand, the narrative and the sketch were needed to provide the highest indication of adequacy for cover ratings.

These results are consistent with previous results. Earlier analysis of variance discussions showed that vegetation structure was important to understanding cover ratings and that the type of vegetation played a dominant role in forage ratings. The type of vegetation was primarily described in the PSR's by the narrative, which was the most important PSR component for forage ratings. Information on vegetation structure was clearly shown in the sketch, but was also contained in the narrative. The combination of these two components was judged adequate by most participants for cover ratings.

The participants' low regard for the photo component was not expected. Was the negative reaction due to photographic quality? Probably not, in our study. We asked the participants to compare several alternative ways of constructing the photo component on a five-level scale ranging from "much inferior" to "equivalent" to "much superior." Comparisons were made between color photocopy, color print, and black and white prints. While about half the respondents thought color prints would have been "superior" to color photocopies, the other half thought they would be "equivalent." On the other hand, over 90 percent of the participants indicated that either color photocopies or color prints were "superior" or "much superior" to black and white prints. The lack of support for the photo component was probably unrelated to topics of color versus black and white or print versus photocopy. Rather, several participants complained that the subject matter portrayed in the photocopy did not correspond to the topic of the PSR. The problem was not that the photocopy was inconsistent with the PSR topic, but rather that the photocopy was insufficient. Each photocopy represented only one of a large number of possible portrayals, all of which were consistent with the topic. For example, while our PSR may accurately depict a seedling/sapling stand, numerous such stands do not look like the one shown in the PSR. The problem was that the topic was far broader than that which could be captured in a single photo, regardless of whether it was a print or photocopy, color, or black and white.

The next thing participants had to deal with was the sorting process, the Q-sort technique. When the study team chose to use a sorting procedure that resulted in each PSR being placed into one of seven habitat quality groups, the concern was whether seven groups were too few to adequately assess habitat quality. The countervailing pressure was that it is more difficult to sort items into more groups. We asked the participants to judge both the ease and the adequacy for alternative grouping arrangements. Because the patterns of response pertaining to cover and forage were virtually the same, they were combined. Table 18 shows a progression from "very easy" to "very difficult" and from "too general" to "far too specific" as the number of sorting groups increased from three to seven. The median participant assessment for the three-group arrangement was "very easy" and "too general." The median assessment for the seven groups actually used was "difficult" and "too specific." We strongly suspect that if more than seven groups were used, the median assessment would have been "very difficult" and "far too specific."

The final Delphi-related topic was feedback. Recall there is no standard format for providing feedback in the Delphi process and that the study team chose to provide feedback in the form of summary evaluations and rating printouts. The exit interview questionnaire asked participants how useful the feedback was in helping them reevaluate PSR's and whether the amount of feedback was correct. Table 19 shows an interesting pattern of response, again combining the near-identical response pertaining to cover and forage. Participants were almost evenly divided on the amount of feedback provided; about half said it was "about right" and about half said it was "too much." This applied both to the summary evaluations and the rating printouts. Usefulness was a different story. The summary evaluations were generally judged to be either "neutral" or "useful." The rating printouts were not as well received. While almost one in five found the printouts "very useful," about a third of the participants found the printouts "harmful." We interpret the response of "harmful" as a participant's reaction against the pressure to change earlier ratings and thus conform to the group norm.

Time Costs.—Costs must be assessed when evaluating Delphi or any other information-developing procedure. There are two kinds of costs—those borne by the study team and those borne by the participants. Study team costs consisted of expenses and personnel time. But because so many aspects of this study were driven by research considerations, rather than simply data gathering, detailed cost records were not maintained. Principal expense items, however, include salaries, costs to produce the sets of PSR, mailing, and computer use for data analysis.

Participant costs consisted entirely of their time. Based on their detailed records, participants on the average, each devoted about 13 hours and 20 minutes to this study. Table 20 shows that the second phase (forage) took about a fourth less time than the first phase (cover), and that each respective iteration generally took less time. There was a substantial range in the amount of time individual participants devoted to the study—as much as nearly a tenfold difference in the case of third-iteration cover. We point to an earlier result: the degree of consensus achieved was strongly related to the

Table 18.—Percentage distribution of judgments of ease in sorting and adequacy in classifying for four alternative grouping arrangements, cover and forage phases combined

Distribution of judgments	Grouping arrangements D:3 strata	C:5 strata	B:5 strata	A:7 strata
		Percent		
Ease				
Very easy	54.6	—	—	—
Easy	31.8	36.4	13.6	—
Moderately difficult	9.1	50.0	59.1	40.9
Difficult	4.6	13.6	27.3	31.8
Very difficult	—	—	—	27.3
Adequacy				
Far too general	36.4	—	—	—
Too general	55.5	59.1	27.3	—
About right	9.1	36.4	36.4	31.8
Too specific	—	4.5	31.8	40.9
Far too specific	—	—	4.5	27.3

Table 19.—Percentage distribution of judgments of amount and usefulness of feedback information, cover and forage phases combined

Distribution of judgments	Type of feedback Summary evaluations	Rating printout
	Percent	
Amount		
Far too little	—	—
Too little	9.1	—
About right	40.9	45.4
Too much	50.0	54.6
Far too much	—	—
Usefulness		
Very harmful	—	—
Harmful	9.1	31.8
Neutral	40.9	13.6
Useful	50.0	36.4
Very useful	—	18.2

Table 20.—Mean and minimum-maximum for participant time involved in study, by phase

Phase	Mean	Min-max
	Minutes	
Cover —1	186.1	79-345
—2	144.8	60-337
—3	100.1	20-195
Total	431.0	190-862
Forage —1	129.2	70-260
—2	129.6	35-302
—3	77.8	30-168
Total	336.6	135-690
Questionnaire	32.2	17-45
Overall	799.8	345-1,546

amount of time devoted to tasks; overall, those participants tending toward the low end of the time range were significantly further away from the consensual standard than were those devoting more time.

Information provided by participants allowed a detailed breakdown of the time devoted to specific activities for each iteration. The listing below shows an approximate average time distribution (cover and forage combined) for the 2.5 hours devoted to first-iteration activities:

Specific activities	First iteration
	Minutes
Three-strata sorting	56
Seven-strata sorting	39
Sorting review	30
Evaluation form	33
	158

The initial three-strata sorting took the most time—almost an hour—to accomplish. While sorting, participants kept track of time needed to sort the first 25 PSR's, the second, and so forth. Respondents averaged about 24 seconds per PSR over the first 25; this dropped by about a fourth to 17 seconds per PSR for the final sortings.

The listing below shows the approximate distribution of time devoted to second and third iteration activities, cover and forage combined:

Specific activities	Second and third iterations
	Minutes
PSR refamiliarization	10
Study rating printout	8
Study summary evaluations	8
Reevaluate, resort	62
Evaluation form (second iteration only)	25
	113

Several weeks usually elapsed between iterations, so the 10 minutes devoted to the first activity was little other than getting reacquainted time. Only about 16 minutes on the average were devoted to reading and evaluating feedback materials, substantially less time than the study team devoted to preparing materials. Then about an hour was spent resorting or rearranging the PSR's, presumably on the basis of the feedback materials.

DISCUSSION

Our study objective was to apply and evaluate the Delphi Method as a means for acquiring useful information for forest management decisions. We chose to focus on elk habitat quality, a topic that was both meaningful and complex. One advantage of the Delphi approach is that it permits investigations into a broad scope of subject matter. A field measurement study with a scope as broad as this Delphi-based study would likely prove impractical, if not infeasible.

It is difficult to judge how well study objectives were met. If satisfaction with outcome is any indication, our purposes were accomplished. The study team is quite satisfied with the study results, both in terms of increasing our understanding of Delphi and our understanding of elk habitat quality. The participants apparently shared this feeling. One of the questions asked in the exit interview questionnaire was how satisfied participants were with the Delphi process. Over 80 percent indicated they were either "satisfied" or "very satisfied," with the remainder indicating "neutral." This degree of satisfaction is heartening for two reasons. First, we doubt that a well-designed and executed field study would be rated substantially different from this Delphi application. Second, considering that all participants had extensive background in biological science and its inherent field orientation, the satisfaction indicated for a social science methodology is somewhat unexpected.

If the success of an information-gathering procedure can be judged on the basis of confidence in results, this Delphi application can again be regarded as successful. The exit interview questionnaire also asked participants how much confidence they had in the (anticipated) final habitat ratings, given knowledge of their involvement and the project's process only. Table 21 shows that the vast majority of participants were "confident" in the habitat quality ratings, both for cover and forage. While the participants had not seen the final outcomes, they were thoroughly familiar with the sorting process, feedback materials, and reevaluations. In a similar manner, an assessment of a field-oriented study is usually judged on the basis of its experimental design, measurement technique, and so forth, not on the basis of the actual measurements obtained. In that regard, we suspect that a well-designed and executed field study would not typically rate any higher than this Delphi application.

In total, this study obtained 11,286 measurements and remeasurements on elk habitat quality. Participants devoted about 147 hours to providing those measurements, or approximately 47 seconds per measurement and remeasurement. This translates to slightly over 18 days of participant time. One advantage of the Delphi process is it does not require face-to-face group participation. A procedure requiring that kind of interaction could easily consume all 18 days in travel time alone. If the average daily wage rate for participants was $200, this study would have cost slightly over $3,600. That amount would not support much field-based data collection. On balance, Delphi appears to be a highly cost-effective means of obtaining these types of resource management data.

Table 21.—Percentage distribution of judgment of confidence in final, anticipated, study results

Confidence	Cover	Forage
Very confident	9.1	—
Confident	72.7	81.8
Neutral	—	18.2
Nonconfident	18.2	—
Very nonconfident	—	—
Total	100.0	100.0

Opportunities to use Delphi results clearly depend on the topic addressed. In general, data gathered by the Delphi process could be used like comparable data gathered by a field study or any other procedure. For example, the habitat quality ratings readily lend themselves to a computer mapping routine that could develop an elk habitat quality map similar to a soil type map. We envision plastic overlays—one for cover and another for forage. These displays could be used to assess spatial forage-cover relationships of elk habitat. Study results could also be used to evaluate management opportunities, particularly those involving vegetation manipulation. Would replacing a sawtimber stand with seedling/saplings improve elk forage? If only a fixed number of acres could be thinned, in which habitat types should the thinning be concentrated to promote maximum forage?

Opportunities to extend Delphi to other applications seem nearly endless. Opportunities are mostly limited by the knowledge, skills, and imagination of the persons applying Delphi, not by Delphi itself. We can readily envision applying the process to questions of long-range environmental consequences of timber harvest activities, habitat requirements for grizzly bear, extramarket valuation, and more. But the most fruitful opportunities to extend Delphi to other applications are best known by natural resource managers who know their specific information needs and priorities. This method takes time and thoughtful planning, but is totally implementable by field managers. Results of this study should increase awareness of Delphi and its potential applications.

Earlier in this paper we criticized some of the nonfield methods being used to develop decision-making information. We feel that the Delphi process is far more satisfactory—capable of giving rise to more credible, defensible information. Whether or not it is the best nonfield data collection technique will probably vary with situation and circumstance. But Delphi is not an alternative to field data collection and scientific experimentation; quality information and advances in scientific knowledge and understanding can result only from scientific exploration involving onsite measurement and experimentation. Yet the Delphi process need not be in conflict with scientific exploration. The two can be complementary. Analysis and evaluation of Delphi-based information can provide testable hypotheses for subsequent scientific inquiry. This study's results contain many such hypotheses. Moreover, Delphi could be used to integrate and synthesize the current state of scientific knowledge to answer questions and address issues about which the state-of-the-art science, by itself, is silent. This may well be an important use of the Delphi Method. For as nature abhors a vacuum, decision makers abhor silence. When decision-making information needs cannot be met with onsite measurement and experimentation, Delphi could be used to fill the void.

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APPENDIX A: COMBINATIONS OF FOREST HABITAT TYPES COMPRISING HABITAT TYPE GROUPS

Habitat types	Habitat type group
Ponderosa pine/bluebunch wheatgrass Ponderosa pine/Idaho fescue	Ponderosa pine
Douglas-fir/bluebunch wheatgrass Ponderosa pine/Idaho fescue	Douglas-fir I
Douglas-fir/ninebark Douglas-fir/snowberry (snowberry and pinegrass phases)	Douglas-fir II
Douglas-fir/pinegrass (pinegrass and kinnikinnick phases) Douglas-fir/dwarf huckleberry	Douglas-fir III
Douglas-fir/blue huckleberry Douglas-fir/twinflower (blue huckleberry phase)	Douglas-fir IV
Douglas-fir/snowberry (bluebunch wheatgrass phase) Douglas-fir/pinegrass (bluebunch wheatgrass and ponderosa pine phases)	Douglas-fir V
Subalpine fir/*Clintonia* Subalpine fir/*Galium* Subalpine fir/twinflower	Subalpine fir I
Subalpine fir/*Menziesia*	Subalpine fir II
Subalpine fir/beargrass	Subalpine fir III
Subalpine fir/wood rush Subalpine fir/grouse whortleberry	Subalpine fir IV
Spruce/horsetail Spruce/*Clintonia* Spruce/dwarf huckleberry	Spruce
Grand fir/*Clintonia* Western hemlock/*Clintonia* Western redcedar/(various types)	Redcedar-grand fir
Whitebark pine-subalpine fir Whitebark pine	Whitebark pine
All hardwoods	Bottomlands
—	Mountain meadow
—	Mountain grassland
—	Mountain brush
	Scree

APPENDIX B: MEAN DEVIATIONS FROM MEDIANS FOR FINAL ELK SUMMER COVER AND FORAGE QUALITY RATINGS BY VEGETATION COVER TYPE, FOREST HABITAT TYPE GROUPS, STAND DENSITY CLASS, AND TREE SIZE CLASS

			Tree size class					
			Cover			Forage		
Vegetation cover types	Forest habitat type groups	Stand density class	Seedling/ sapling	Pole-timber	Saw-timber	Seedling/ sapling	Pole-timber	Saw-timber
Hardwoods	Bottomlands	Poor	0.5		0.9	0.3		0.7
		Medium		0.6			0.5	
		Well	.3		.7	.7		.5
	Spruce	Poor	.4		.7	.3		.4
		Medium		.3			.2	
		Well	.5		.6	.4		.2
Ponderosa pine	Ponderosa pine	Poor	.3		1.0	.1		.3
		Medium		.6			.1	
		Well	.5		.9	.3		.2
	Douglas-fir I	Poor	.5		.9	.2		.2
		Medium		.5			.2	
		Well	.4		.7	.2		.3
	Douglas-fir II	Poor	.5		1.1	.6		.5
		Medium		.5			.4	
		Well	.5		.6	.5		.5
	Douglas-fir III	Poor	.3		.8	.6		.4
		Medium		.5			.7	
		Well	.4		.5	.5		.5
	Douglas-fir V	Poor	.5		1.1	.2		.2
		Medium		.5			.4	
		Well	.4		.6	.2		.3
	Scree	Poor	.1		.5	0		0
		Medium		.5			0	
		Well	.5		.5	0		0
Douglas-fir	Douglas-fir I	Poor	.4		.6	.2		.4
		Medium		.3			.2	
		Well	.4		.6	.5		.4
	Douglas-fir II	Poor	0		1.1	.5		.3
		Medium		.3			.5	
		Well	.5		.6	.5		.5
	Douglas-fir III	Poor	.4		1.1	.5		.4
		Medium		.1			.5	
		Well	.5		.5	.4		.4
	Douglas-fir IV	Poor	.2		.5	.5		.5
		Medium		.4			.5	
		Well	.7		.4	.5		.4
	Douglas-fir V	Poor	.5		1.2	.5		.3
		Medium		.5			.2	
		Well	.4		.5	.1		.2
	Subalpine fir I	Poor	.4		.6	.6		.1
		Medium		.4			.6	
		Well	.3		.5	.4		.1
	Scree	Poor	.1		1.1	0		0
		Medium		.8			0	
		Well	.4		.6	0		0
Lodgepole pine	Douglas-fir III	Poor	.3		.6	.7		.4
		Medium		.3			.5	
		Well	.3		.3	.5		.5
	Douglas-fir IV	Poor	.2		.8	.5		.5
		Medium		.4			.5	
		Well	.3		.4	.3		.5

(con.)

APPENDIX B. (Con.)

			Tree size class					
			Cover			Forage		
Vegetation cover types	Forest habitat type groups	Stand density class	Seedling/ sapling	Pole-timber	Saw-timber	Seedling/ sapling	Pole-timber	Saw-timber
	Subalpine fir I	Poor	.4		.6	.3		.5
		Medium		.3			.5	
		Well	.5		.5	.2		.1
	Spruce	Poor	.5		.9	.5		.4
		Medium		.4			.2	
		Well	.5		.5	.2		.5
	Subalpine fir II	Poor	.4		.6	.5		.6
		Medium		.7			.4	
		Well	.9		.4	.5		.5
	Subalpine fir III	Poor	.5		1.0	.5		.5
		Medium		.4			.6	
		Well	.5		.4	.5		.5
	Subalpine fir IV	Poor	.5		.9	.8		.8
		Medium		.5			.7	
		Well	.5		.5	.7		.7
Western larch	Subalpine fir I	Poor	.5		.8	.2		.4
		Medium		.5			.5	
		Well	.4		.5	.2		.4
Engelmann spruce	Subalpine fir I	Poor	.4		.5	.4		.3
		Medium		.3			.3	
		Well	.4		.4	.4		.3
	Subalpine fir II	Poor	.6		.5	.5		.7
		Medium		.6			.4	
		Well	.5		.1	.7		.5
	Subalpine fir IV	Poor	.5		.8	.6		.6
		Medium		.5			.5	
		Well	.3		.5	.6		.6
	Spruce	Poor	.5		.9	.3		.5
		Medium		.7			.2	
		Well	.4		.3	.2		.2
Grand fir	Western redcedar/ grand fir	Poor	.6		.7	.5		.6
		Medium		.7			.6	
		Well	.8		.2	.4		.6
Western redcedar	Western redcedar/ grand fir	Poor	—		.9	—		.5
		Medium	—	.4		—	.4	
		Well	—		.3	—		.7
Subalpine fir	Subalpine fir II	Poor	.6		.5	.5		.4
		Medium		.6			.5	
		Well	.6		.2	.2		.5
	Subalpine fir III	Poor	.4		.6	.7		.5
		Medium		.5			.6	
		Well	.5		.6	.7		.4
	Subalpine fir IV	Poor	.5		.7	.7		.5
		Medium		.4			.6	
		Well	.7		.5	.7		.6
Whitebark pine	Subalpine fir III	Poor	.5		1.1	.6		.5
		Medium		.5			.6	
		Well	.5		.4	.5		.6
	Whitebark pine	Poor	.5		.8	.5		.5
		Medium		.5			.5	
		Well	.5		.5	.5		.5
Forbs and grasses	Mountain meadow	—	—	.1	—	—	0	—
	Mountain grassland	—	—	.1	—	—	.9	—
Shrubs	Mountain brush	—	—	.6	—	—	.5	—

APPENDIX C: THREE-CLASS DICHOTOMOUS KEY FOR DISCRIMINANT ANALYSIS OF ELK SUMMER COVER AND FORAGE QUALITY

Cover

If: $+4.20 + 2.79(UD1) + 2.20(TS1) + 0.73(M1) - 10.60(C2) - 9.79(C3) - 7.31(C4) - 11.00(C5) > 0$ → Low
↓
otherwise

If: $+3.45 + 1.97(TS1) - 1.39(TS2) + 3.01(M1) - 1.12(T1) - 1.88(C3) - 7.02(C4) > 0$ → Medium
↓
otherwise
↓
High

. . . Overall correct classification: 84%

Forage

If: $-14.17 + 14.58(UD1) + 2.77(E1) + 9.27(TS1) - 2.50(TS2) - 4.35(M1) + 1.08(C2) > 0$ → Low
↓
otherwise

If: $-17.97 - 1.45(UT1) + 20.91(TS1) + 17.74(TS2) + 4.37(M1) + 18.01(T1) + 6.46(C1) + 8.33(C2) + 5.78(C3) + 4.82(C4) + 7.48(C5) > 0$ → Medium
↓
otherwise
↓
High

. . . Overall correct classification: 92%

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-676-039/20026

Schuster, Ervin G.; Frissell, Sidney S.; Baker, Eldon E.; Loveless, Robert S., Jr. The Delphi Method: application to elk habitat quality. Research Paper INT-353. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 32 p.

Study was designed not only to apply and evaluate the Delphi Method but also to measure elk habitat quality. Elk habitat was restricted to summer cover and forage in western Montana. Eleven elk habitat experts participated in rating habitat quality. Statistical analyses were conducted, relating habitat quality to factors such as cover type and stand density. Analyses of the Delphi Method pertained to consensus, number of participants, and more.

KEYWORDS: Delphi, information, decision-making, elk habitat, wildlife management

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Research Paper
INT-354

November 1985

Ecological Genetics of *Pinus contorta* in the Lower Snake River Basin of Central Idaho

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RESEARCH SUMMARY

Genetic differentiation of 89 populations of *Pinus contorta* primarily from central Idaho was assessed by a series of three studies involving (1) growth and development in field environments, (2) the periodicity of shoot elongation in the greenhouse, and (3) freezing tolerance in the laboratory. Population differentiation was detected for a variety of traits that included 3-year height, leaf length, freezing tolerance, and the pattern of shoot elongation. Regression models related as much as 77 percent of the variance among population means to the elevation and geographic location of the seed origin. Elevational clines were steep but geographic clines were gentle. Consequently, if maladaptation is to be controlled in artificial reforestation, seed transfer should be restricted severely for elevation but may be relatively liberal geographically. Detailed practical guidelines for regulating seed movement will be presented separately.

Ecological Genetics of *Pinus contorta* in the Lower Snake River Basin of Central Idaho

G. E. Rehfeldt

INTRODUCTION

Adaptation of populations to the physical environment is the subject of a series of studies on the ecological genetics of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) from the Rocky Mountains. The present study of populations from central Idaho is intended to (1) assess adaptive differentiation among populations and (2) relate patterns of genetic variation to geography, topography, physiography, and climate.

Adaptive differentiation of lodgepole pine populations in both the United States (Rehfeldt 1985b; Stoneman 1985; Hoff 1985) and Canada (Lindgren and others 1980; Hagner 1980; Ying and others 1985) parallels environmental gradients. Consequently, clines in the rugged Rocky Mountains of the United States tend to be steep, while those for regions of dissected plateaus in British Columbia tend to be gentle. Regardless of whether geographic clines predominate, as in British Columbia (Ying and others 1985), or whether altitudinal clines predominate, as in the Rocky Mountains of the United States (Rehfeldt 1985b), populations from relatively mild environments display a high growth potential and low cold hardiness, while populations from severe environments exhibit a low growth potential and high hardiness.

Consequently, seed transfer for reforestation in northern Idaho (Rehfeldt 1983), Utah (Rehfeldt 1985a), and central Oregon (Stoneman 1985) must be restricted greatly if maladaptation and resultant losses in productivity are to be controlled. Practical application of the present study involves developing seed transfer guidelines for lodgepole pine in central Idaho.

MATERIALS AND METHODS

Population differentiation was studied in seedlings from 89 populations. Of these populations, 80 represented the geographic distribution and ecologic amplitude of the species in the lower Snake River Basin in central Idaho. Eight populations were from the Cascade Mountains of south-central Oregon, and one represented a small disjunct population from Deadline Ridge in southern Idaho (fig. 1). Seedlings from the 89 populations were used in separate studies of: (1) growth and development in field environments, (2) periodicity of shoot elongation in a greenhouse, and (3) cold hardiness in the laboratory. Because cone collections, experimental procedures, and statistical analyses are detailed in the first paper of this series, which involved populations from the Wasatch and Uinta Mountains of Utah (Rehfeldt 1985a), only an outline follows.

Growth and Development

One set of seedlings from each of the 89 populations was grown for 6 months in plastic containers (10 in^3) in a shadehouse at Moscow, ID (lat. 48.5° N., long. 116.7° W.). In the fall, seedlings were transplanted into two environments, 2,200 feet and 5,000 feet elevation, at

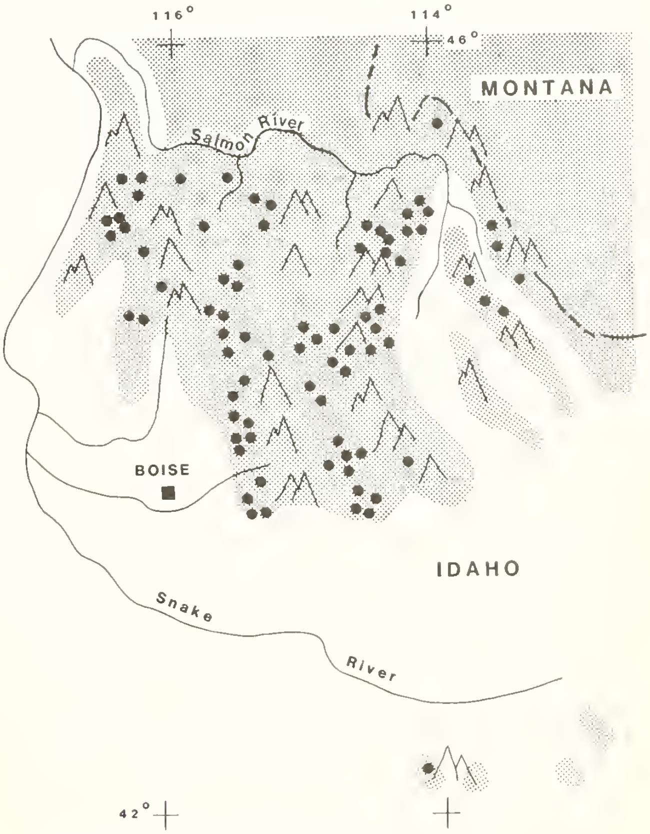


Figure 1.—Geographic distribution of *Pinus contorta* (shading, according to Little 1971) within the region of study and location of populations (symbols).

the Priest River Experimental Forest, 150 miles north of Moscow. Eight seedlings spaced at 1 foot and 0.5 foot at low and high elevation sites, respectively, were planted in row plots, separated by 1.5 feet and 1 foot at the respective sites. Three blocks were established at each site, and both plantings were maintained under intensive management.

The performance of individual seedlings was described by four variables for which differentiation of Utah populations had been pronounced: (1) height—seedling height after 3 years; (2) late growth—amount of the 3-year predetermined shoot that elongated after the fourth week of elongation in the respective environments; (3) leaf length—the length of a leaf near the center of the 3-year shoot; and (4) adjusted height—3-year height adjusted by regression on 2-year height. By representing the increment from a common 2-year height, adjusted height is relatively independent of previous environmental (such as transplanting shock) and genetic effects and thereby is capable of reflecting adaptation of populations to a particular environment for a single growing season.

In addition, scores were made of the presence or absence of injury from a freeze (16 °F) that occurred in mid-May at the low elevation site. Injuries ranged from death of the developing shoot to reductions in internode lengths near the shoot tip.

To account for heterogeneous variances at the two test environments, data were transformed to standard normal deviates (Steel and Torrie 1960) for each test site and the deviates were analyzed according to a model of random effects. The model estimated: (1) main effects for test environments, blocks within environments, and populations; (2) the interaction of populations × environments; (3) an experimental error, composed of the interaction of populations × blocks within environments; and (4) a residual error. As a result of the transformations, mean squares associated with the main effects of test environments were zero. A harmonic mean of 7.20 reflected the number of seedlings represented in each block.

Injury from the spring frost was analyzed according to a model of random effects, which estimated effects of blocks, populations, and an error.

Periodicity of Shoot Elongation

Another set of seedlings grew for 1 year in plastic containers (45 in^3) in a shadehouse at Moscow. Each population was represented by nine seedlings in each of three blocks. In early March of the second growing season, seedlings were moved into a greenhouse before shoot elongation had begun. Greenhouses were maintained under natural lighting. Temperatures were about 75 °F during the day and 55 °F at night. All seedlings were measured three times each week until elongation of the preformed bud had ceased.

As described by Rehfeldt and Wykoff (1981), shoot elongation of individual trees was expressed mathematically by a logistic function that included a hyperbolic time term. Regression statistics allowed calculation of the following variables for describing periodicity of shoot elongation of individual seedlings: (1) initiation of growth—the day on which 0.1 inch of cumulative growth had occurred; (2) cessation of growth—the day on which all but 0.1 inch of growth had occurred; (3) duration of growth—the number of days between initiation and cessation; (4) rate of growth—elongation per day during the period of maximum elongation; and (5) total elongation.

Population differentiation was assessed according to least squares analyses of random effects that estimated main effects for populations and blocks, the interaction of populations × blocks, and an error. A harmonic mean of 8.81 reflected the number of seedlings representing each population in each block.

Cold Hardiness

To estimate the relative cold hardiness of populations in early autumn, laboratory tests of freezing tolerance were made according to the general procedures of Levitt (1972). Mature leaves were collected in late September from near the center of the 3-year shoot of trees represented in field tests at 5,000 feet elevation.

Four sets of eight leaves were collected from each eight-tree plot. Each set contained one leaf from each tree. One set of leaves from each plot was exposed to one of four test temperatures (−4 °F, −6 °F, −10 °F, and −12 °F) by cooling at the rate of 10 °F/h. Injured leaves were identified visually by the presence of discolored and flaccid tissue (Rehfeldt 1980). Population differentiation for the proportion of injured leaves from each plot was assessed from a model of random effects that allowed estimation of main effects for populations, blocks, and test temperatures; three two-way interactions; and a residual.

Patterns of Variation

Geographic patterns of genetic variation were assessed from a series of regression analyses that fitted independent variables describing the origin of populations to the array of population means. Because the primary purpose of these analyses was to describe genetic patterns of variation for the lower Snake River Basin, regression analyses considered only the 80 representative populations. The sequence of regression analyses concentrated first on the relationship between performance and elevation of the seed source, and second on geographic patterns of variation that were independent of elevation. Adequacy of a model was judged according to the goodness of fit (R^2), residual variance ($s_{y \cdot x}$), and geographic or ecologic patterns displayed by residuals (Draper and Smith 1966).

Elevational models considered both a linear and quadratic relationship between performance and elevation of the seed source. Deviations from the best fitting elevational regressions were then used as dependent variables for considering geographic patterns of variation that were independent of elevation. The geographic model included four independent variables plus their squares: latitude, longitude, northwest departure, and northeast departure. The latter two variables were obtained by rotating the grid of latitude and longitude by 45°. Thus, eight independent variables were included in the model, which was fitted with a stepwise regression program for maximizing R^2 (Barr and others 1979). Finally, elevation of the seed source was added to the independent variables of the best fitting geographic model in order to estimate the joint determination of performance by geography and elevation for those variables in which previous models had been significant.

RESULTS

Because each study was autonomous, the results of each are presented separately but are considered jointly in establishing patterns of genetic variation.

Growth and Development

The effects of planting environment on growth and development of seedlings were pronounced for all traits (table 1). Trees growing at low elevation were much taller and had longer leaves than those at high elevation. Adjusted heights show that even if all trees had been the same height at age 2, those growing at low elevation would still have been tallest after 3 years. Late growth, defined as the proportion of the predetermined shoot that elongated after the fourth week, was measured at the low elevation approximately 5 weeks earlier than at the high, and therefore also was affected tremendously by the environment.

For nearly all variables, the range in population mean values was considerably different at the two planting environments (table 1). For these ranges to differ greatly illustrates the heterogeneous variances that required adjustment before statistical analyses were made.

By accounting for over a third of the total variance, effects of populations were pronounced for 3-year height and frost injury (table 2). These strong effects are illustrated by mean differences between populations of as much as 1 foot in height and 58 percent in trees injured by frost. On the average, trees damaged by frost were 2.5 inches shorter after 3 years than uninjured trees from the same population. Relatively weak effects for late growth contrast sharply with previous results (Rehfeldt 1985a) and likely are due to the late stage of elongation at which current measurements were begun: the average tree produced only 12 percent of the 3-year shoot as late growth. Consequently, mean values for populations ranged from only 0.6 inch to 1.4 inches. Populations also differed by as much as 0.8 inch in leaf length. But no differences could be detected among populations for adjusted height, a result that is partially influenced by the significant regression of 3-year height on 2-year height, which accounted for 70 percent of the variance in 3-year height of individual trees.

Significant interactions of populations and environments were apparent for leaf length and adjusted height. The interaction for leaf length is best interpreted as sampling errors associated with slightly different estimates of mean values for a given population at the two planting sites. But the interaction for adjusted height developed from divergent performance of individual populations in the two environments. This interaction will be considered later when patterns of variation for mean values of this trait are considered from both test sites. The size of this interaction, however, explains the lack of main effects of populations for adjusted height.

Table 1.—Mean values according to test environment and range of population means in each environment

Variable		Mean values at		Range in population means at	
		2,200 ft	5,000 ft	2,200 ft	5,000 ft
Late growth	(inches)	1.2	0.6	1.3	0.4
Leaf length	(inches)	2.8	2.4	0.9	1.1
Height	(inches)	16.6	13.4	15.5	7.4
Adjusted height	(inches)	16.0	14.0	6.8	3.1
Frost injury	(percent)	15	—	58	—

Table 2.—Results of analyses of variance for growth and development presented as intraclass correlations, the ratio of individual variance components to the sum of all components

Source of variance	Variable				
	Late growth	Leaf length	Height	Adjusted height	Frost injury
Environments	0	0	0	0	0
Blocks in environment	0.04**	0.04**	0.03**	0.01*	0.01*
Populations	.05**	.07**	.41**	−.01	.33**
Environment × population	0	.05**	.02**	.31**	—
Experimental error	.11**	.08**	.05**	.04**	—
Within plots	.80	.76	.49	.72	.67

*Statistical significance of the F-value at the 5 percent level of probability.
**Statistical significance of the F-value at the 1 percent level of probability.

Periodicity of Shoot Elongation

The logistic function described periodicity of shoot elongation of individual trees nearly perfectly. Values of R^2 ranged from 0.93 to essentially 1 while averaging 0.99. Analyses of variance detected significant differences (fig. 2) among populations for all variables but were particularly strong for the duration, cessation, and amount of shoot elongation (table 3). For these variables, main effects of populations accounted for more than 30 percent of the total variance. Differences between populations were as large as 18 days in cessation, 17 days in duration, 2 days in initiation, 0.1 inch per day in rate, and 3.2 inches in the amount of elongation. Most of the differences among populations in the initiation of shoot elongation resulted from delayed initiation of sources from the Cascade Mountains. Differences among populations from central Idaho amounted to only 1 day.

Cold Hardiness

Effects of test temperatures dominated analyses of variance (table 4). These effects are associated with a range in injury from 27 percent at −4 °F to 70 percent at −12 °F. Effects of populations were significant and accounted for 12 percent of the total variance. Mean differences among populations amounted to as much as 70 percent injured leaves.

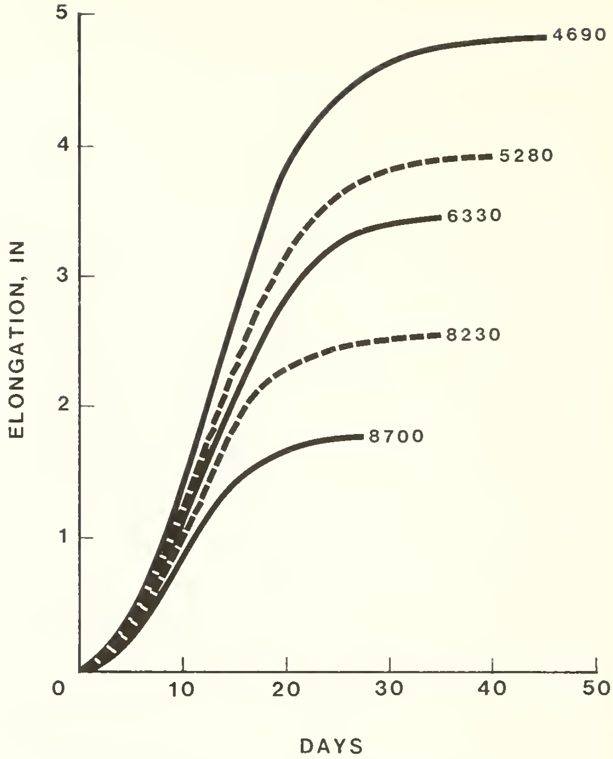


Figure 2.—Periodicity of shoot elongation for populations from a range of elevations (feet) that represented maximum differences in response.

Table 3.—Results of analyses of variance for periodicity of shoot elongation presented as intraclass correlations, the ratio of a variance component to the sum of all components

Source of variance	Initiation	Duration	Rate	Cessation	Elongation
Blocks	0.01*	0.01*	0.02*	0.01*	0.02*
Populations	.12*	.29*	.14*	.30*	.37*
Interaction	.10*	.04*	.17*	.03*	.12*
Within plots	.77	.73	.67	.66	.49

*Statistical significance of the F-value at the 1 percent level.

Table 4.—Results of analyses of variance of freezing tests presented as intraclass correlations, the ratio of a variance component to the sum of all components

Source of variance	Intraclass correlation
Blocks	0.01*
Temperatures	.23**
Populations	.12**
Populations × temperatures	0
Residual[1]	.64

*Statistical significance of the F-value at the 5 percent level.
**Statistical significance of the F-value at the 1 percent level.
[1] Composed of the two interactions involving populations.

Patterns of Variation

Elevation of the seed source had a pronounced effect on performance of populations. Elevational models accounted for more than 60 percent of the variance between populations for four variables and were statistically significant for all variables except the initiation of shoot elongation (table 5 and fig. 3). As elevation of the seed source increased, growth potential decreased, largely because of an associated decline in late growth and in the rate, duration, and cessation of shoot elongation. Leaf lengths also declined with increasing elevation, but freezing tolerance increased. Quadratic models provided a significant reduction in the residual mean square of the linear model for only late growth, leaf length, and adjusted height at 2,200 feet.

Table 5.—Coefficients of determination (R^2) for regression analyses relating genetic variation to geographic and physiographic variables

Variable	Elevational models Linear	Elevational models Quadratic	Geographic model	Combined model
Growth and development				
Late growth	0.17**	0.21**	0	—
Leaf length	.36**	.39**	0.12**	0.52**
Height	.69**	.69**	.14**	.74**
Adjusted height (2,200 ft)	.42**	.47**	.23**	.60**
Adjusted height (5,000 ft)	.21**	.21**	.09*	.28**
Frost injury	.42**	.42**	.18**	.54**
Periodicity of shoot elongation				
Initiation	0	.01	0	—
Duration	.64**	.64**	.21**	.71**
Rate	.48**	.50**	.07*	.52**
Cessation	.64**	.64**	.22**	.72**
Elongation	.66**	.67**	.23**	.73**
Cold hardiness				
Injury	.42**	.42**	.08	—

*Statistical significance at the 5 percent level of probability.
**Statistical significance at the 1 percent level of probability.

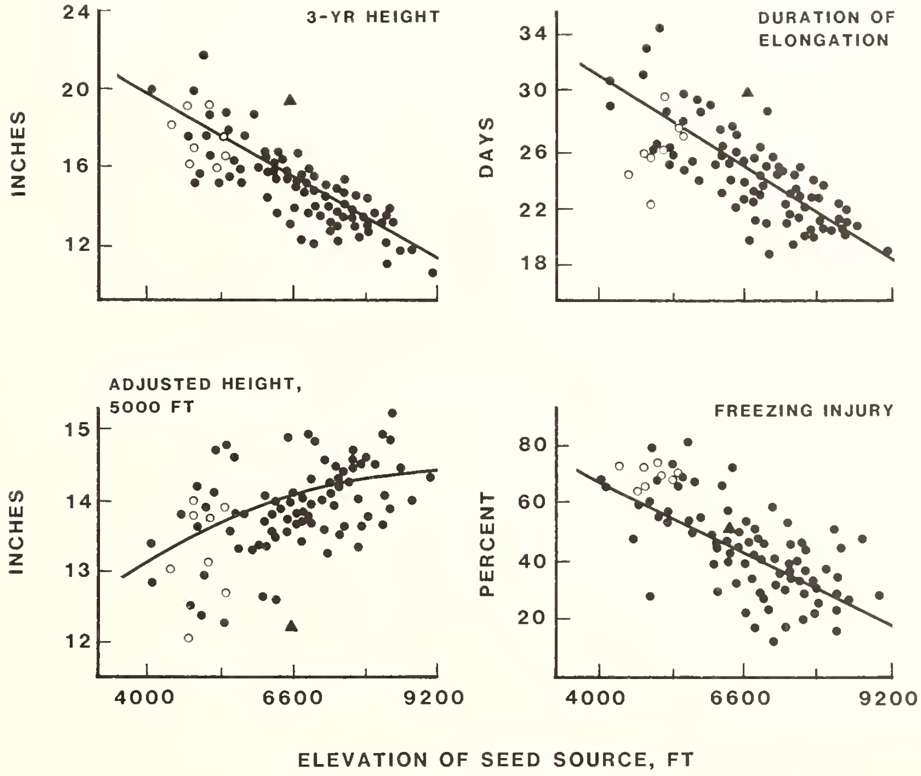


Figure 3.—Population means for four variables plotted by elevation of the seed source: • = lower Snake River Basin; O = Cascade Mountains; ▲ = Deadline Ridge.

The geographic model (table 5) was statistically significant for all variables except late growth, initiation of shoot elongation, and freezing injury. This model, however, accounted for less than a quarter of the variance in dependent variables that was not explained by elevation. Thus, the geographic model accounted for less than 10 percent of the total variance among populations. Consequently, elevational clines tend to be steep, but geographic clines tend to be gentle. Geographic variables plus elevation (the combined model) accounted for 28 to 74 percent of the variance among populations.

Geographic patterns of genetic variation that are independent of elevation are presented in figure 4 for several traits. These patterns were generated from values predicted from the geographic model. The contour interval is scaled to a value equaling half the least significant difference (Steel and Torrie 1960) among populations at the 80 percent level of probability [½ *lsd*(0.2)]. Because values of *lsd* were calculated from the analysis of variance (table 2), contours represent about half the geographical distance associated with population differentiation at the 80 percent level of probability. Contouring was begun with the overall mean, the zero deviation from the elevational regression.

All variables for which the geographic model was significant presented similar patterns of genetic variation. Those variables selected for figure 4 illustrate patterns of greatest divergence. In general, populations from the Salmon River drainage in the northeast portion of the region are of highest growth potential and least hardiness. Clines of decreasing growth potential and increasing hardiness radiate to the south and west. Only leaf length presents a divergent pattern: leaf lengths decline from west to east. Similar elevational and geographic clines result from significant intercorrelations among variables (table 6). Particularly noteworthy are the correlations among variables associated with growth potential. Whether measured in the field or greenhouse, these correlations were particularly strong (r>0.75).

Regression analyses also clarify the interaction of populations and test environments for adjusted height (table 2). Elevational models showed that population

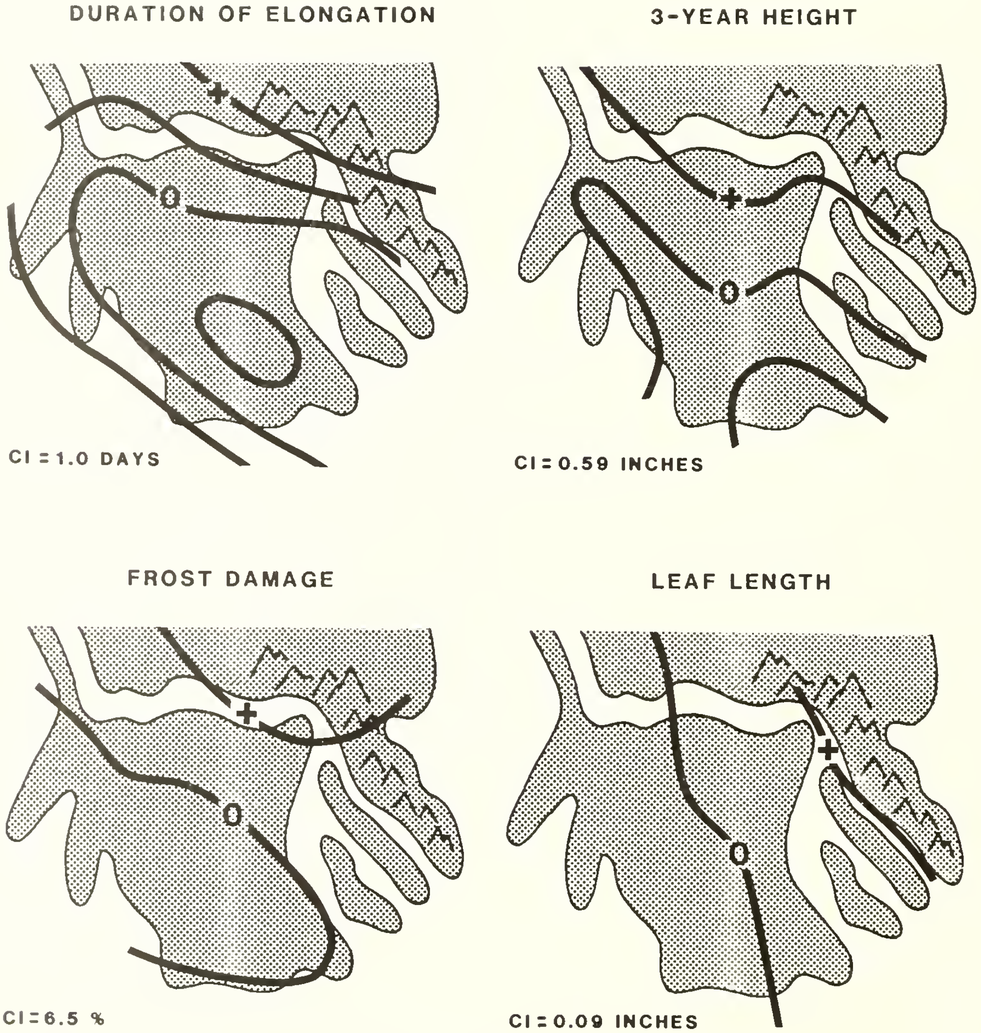


Figure 4.—Geographic patterns of variation that are independent of elevation. Shading marks the distribution of lodgepole pine in relation to the Bitterroot Range. C.I. = the contour interval, which is scaled to a value of ½*lsd* (0.2). The zero contour represents the mean of all populations standardized for elevation.

Table 6.—Correlation matrix relating population means for all studies[1]

Variable	Code	LL	H	AH1	AH2	FI	I	D	R	C	EL	IN
Growth and development												
Late growth	LG	0.53	0.39	0.40	−0.17	0.12	0.04	0.39	0.31	0.39	0.40	0.30
Leaf length	LL		.61	.57	−.26	.43	.04	.61	.57	.62	.64	.47
Height	H			.76	−.49	.60	.05	.87	.77	.88	.89	.26
Adjusted height (2,200 ft)	AH1				−.12	.54	.10	.73	.53	.74	.72	.52
Adjusted height (5,000 ft)	AH2					−.16	−.01	−.46	−.30	−.46	−.42	−.33
Frost injury	FI						−.10	.54	.51	.53	.57	.41
Periodicity of shoot elongation												
Initiation	I							−.04	−.24	.03	−.11	.30
Duration	D								.77	.99	.95	.54
Rate	R									.76	.91	.38
Cessation	C										.94	.56
Elongation	EL											.52
Cold hardiness												
Injury	IN											

[1]Coefficients of absolute value >0.22 are statistically significant at the 5 percent level.

means for adjusted height measured at high elevation were positively correlated with elevation of the seed source (fig. 3). But when measured at low elevations, population means were negatively associated with the elevation of the seed source. Thus, between years 2 and 3, trees from high elevations were beginning to perform the best at the high elevation site, while trees from relatively mild environments at low elevation were expressing the best performance on the site at low elevation.

The performance of populations from geographic regions peripheral to the region of study is presented in table 7 relative to that expected for populations in central Idaho from similar elevations. Populations from the Cascades of central Oregon expressed both a lesser growth potential and lesser hardiness than populations from central Idaho. These differences are particularly emphasized in studies of shoot elongation. Populations from the Cascades started elongation late, ceased early, and grew at a slow rate. In contrast to the comparative performance of Cascade populations, the disjunct southern population from Deadline Ridge expressed a growth potential that exceeded that of populations at similar elevations in central Idaho.

Table 7.—Average difference between the observed performance of peripheral populations and that expected from the elevational regression for populations from central Idaho

Variable		Cascade Range	Deadline Ridge
Growth and development			
Late growth	(inches)	−0.00	0.08
Leaf length	(inches)	−.28	.29
Height	(inches)	−.46	4.34
Adjusted height (2,200 ft)	(inches)	.19	1.48
Adjusted height (5,000 ft)	(inches)	−.28	−4.35
Frost injury	(percent)	−2.00	9.10
Periodicity of shoot elongation			
Initiation	(days)	.90	.10
Duration	(days)	−2.30	5.40
Rate	(in/day)	−.00	+.00
Cessation	(days)	−.06	.20
Elongation	(inches)	−.48	.90
Cold hardiness			
Injury	(percent)	10.20	1.90

DISCUSSION

Genetic differentiation among populations from the lower Snake River Basin, like that for populations from northern Idaho (Rehfeldt 1983), Utah (Rehfeldt 1985a) and Oregon (Stoneman 1985), occurs along relatively steep clines. Differentiation was detected for a variety of traits, most of which were intercorrelated. Strong intercorrelations among adaptive traits result from either or both genetic linkage and parallel selection. Regardless, coherence (Clausen and Hiesey 1960) describes the system of genetic variability for a species such as lodgepole pine that is physiologically specialized for specific environments. Populations from mild environments are of high growth potential and low hardiness. Populations from severe environments are of high hardiness and low growth potential. Adaptation in lodgepole pine can be viewed as a balance between selection for high growth potential in mild environments and selection for high cold hardiness in severe environments.

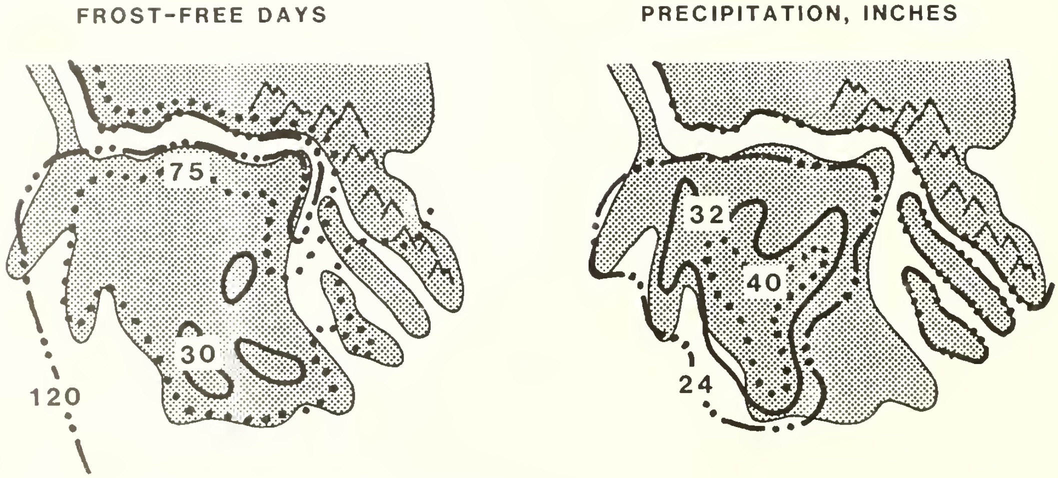
Because adaptive clines parallel environmental gradients, it is not surprising that elevational clines are pronounced. Temperatures and, consequently, the length of the growing season decrease as elevation increases. Regression coefficients indicated that populations separated by 3,000 feet are expected to differ, for example, by 35 percent in 3-year height, 25 percent in injury from spring and fall freezing, and 0.3 inch in leaf length.

Geographic patterns of genetic variation also tend to correspond to environmental gradients, particularly those gradients reflected by the frost-free period (fig. 5). The influence of the Salmon River drainage on both climatic and genetic gradients (figs. 4 and 5) is particularly striking. The northeast portion of this drainage is not only characterized by a relatively mild climate, but also presents to the distribution of lodgepole pine the largest acreage of relatively mild climate in central Idaho. Consequently, it is the performance of populations from the northeast that drives the geographic regression. These populations are of highest growth potential and least hardiness. Toward the south and southwest, however, the mild climate deteriorates rapidly. Populations correspondingly express declining growth potential and increasing hardiness.

Elevational clines are much steeper than the geographic. A comparison of these clines is possible from figure 4 in which each geographic band, situated between any two contours, is standardized for elevation. Each band is equivalent to the amount of genetic variation that occurs across 345 feet, 425 feet, 1,050 feet, and 1,150 feet of elevation for 3-year height, duration of elongation, frost injury, and leaf length, respectively. Thus, in a region that spans 150 miles from north to south, geographic clines for those variables in which population differentiation was pronounced (table 5) are equivalent to an elevational cline of about 1,000 feet at a single locality.

Patterns of adaptive variation have direct implications in forest management. To limit maladaptation in planted trees, seed transfer guidelines must reflect adaptation. One estimate of an appropriate limit to seed transfer involves the smallest geographic or elevational interval across which differentiation can be detected (Rehfeldt 1979). This interval is estimated by the ratio $lsd(0.2)/b$, where b is the regression coefficient and $lsd(0.2)$ is derived from the analysis of variance as the least significant difference among population means at the 80 percent level of probability. (A rather low level of probability is used to avoid accepting no differences when differences actually exist.)

Elevational intervals associated with $lsd(0.2)$ included 680 feet for 3-year height, 890 feet for the duration of shoot elongation, 1,560 feet for freezing injury, 2,300 feet for leaf length, and 3,440 feet for late growth. These intervals suggest that the maximum elevational limits for biologically sound seed zones should not be much greater than 700 feet. This means that the transfer of seed from a single source should be limited to ±350 feet. Nevertheless, considerable genetic differentiation is expected across seed zones that are only 700 feet thick. These differences, for instance, amount to about 8 percent in 3-year height and nearly 6 percent in susceptibility to cold injury.


FROST-FREE DAYS

PRECIPITATION, INCHES

Figure 5.—Geographic patterns in precipitation and frost-free period for the lower Snake River Basin (from U.S. Department of Commerce 1968).

Geographic patterns of variation (fig. 4) were scaled to a value of $\frac{1}{2}lsd(0.2)$, and therefore, lateral transfers of seed should be limited to about ±1 contour. This means that two geographic zones are sufficient for lodgepole pine in the lower Snake River drainage.

The appropriate size of seed zones should be practical administratively and economically. Thus, limits to seed transfer must accommodate biology and economics, while being operationally feasible. When, however, feasibility and economics demand an alteration in the guidelines proposed above, it should be remembered that each geographic band of figure 4 is equivalent genetically to a relatively small elevational interval within a locality. Consequently, the geographic limits should be compromised. From the biological viewpoint, seed zones for the lower Snake River Basin should be considered as elevational zones with geographic stratification.

Regardless, populations of lodgepole pine from the lower Snake River display patterns of genetic variation that seem to typify the adaptation of the species to heterogeneous environments in other geographic localities. Populations appear to be physiologically attuned to specific environments, clines are steep, and genetic differences occur across relatively small environmental intervals. Differentiation among populations is easy to detect experimentally and is closely related to geography and elevation of the seed origin. Therefore, seed transfer in artificial reforestation should be limited greatly.

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Genetic differentiation of 89 populations of *Pinus contorta* primarily from central Idaho was studied in field, greenhouse, and laboratory tests. Analyses of variables reflecting growth potential, morphology, cold hardiness, and periodicity of shoot elongation revealed population differentiation for a variety of traits. Regression models related as much as 77 percent of the variance among population means to the elevation and geographic location of the seed source. For genetic variation to be arranged along relatively steep environmental clines implies pronounced adaptive differentiation. As a result, seed transfer in reforestation should be restricted severely if maladaptation is to be controlled.

KEYWORDS: microevolution, adaptation, population differentiation, seed zones, seed transfer

United States
Department of
Agriculture

Forest Service

Intermountain
Research Station
Ogden, UT 84401

Research Paper
INT-355

December 1985

Breeding Bird Responses to Diameter-Cut Logging in West-Central Idaho

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CLEMSON UNIVERSITY
FEB 25 1986
PUBLIC DOCUMENTS

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ACKNOWLEDGMENTS

I gratefully acknowledge the valuable field and office assistance of James R. Groves, Robert Jordan, Stan Baker, and Shiela Donovan. James F. Rathbun, District Ranger, Boise National Forest, arranged for part-time housing facilities near the study site. Walter F. Megahan, James L. Clayton, Timothy L. Mosko, Dale O. Hall, and Russell A. Ryker, Forestry Sciences Laboratory, Boise, ID, provided support and contributed in many other ways.

RESEARCH SUMMARY

Populations of breeding birds responded differently to structural changes in a Douglas-fir forest caused by diameter-cut logging. Little change occurred in total bird density or standing crop biomass of birds either between years or between logged and unlogged plots. But there were pronounced changes in the composition of the breeding bird community. Logging the forest resulted in increases in numbers for species that require more open habitats and decreases in populations for species that require more closed habitats. Several species maintained relatively stable densities on both logged and unlogged plots.

The number of breeding bird species (species richness) was consistently higher on logged plots than on unlogged plots and trended upward each year after logging. Ten species were territorial only in the logged forest. One species that was territorial in the unlogged forest was absent from the logged forest. There were no clear patterns in bird species diversity either between years or between logged and unlogged plots. The evenness (equitability) component of bird species diversity declined each year after logging.

Two categories (guilds) of birds—the foliage foragers and the timber gleaners—were less numerous on logged plots. The timber-gleaning guild, the most severely affected, dropped to only one-third of prelogging densities in the third year after logging. The ground-foraging and flycatching guilds were more numerous on logged plots. Of nine species represented in the ground-foraging guild, each was proportionately more abundant in the logged forest than in the unlogged forest. The timber-drilling guild, at least in total, was a relatively stable component of the breeding bird population.

Patterns observed in this study, and other studies that were compared, suggest consistencies of response among certain breeding bird species to logging in western coniferous forests.

Breeding Bird Responses to Diameter-Cut Logging in West-Central Idaho

Dean E. Medin

INTRODUCTION

The structure of forest vegetation is an important bird niche dimension (Anderson and Shugart 1974; Conner and others 1983; James 1971; Karr and Roth 1971; MacArthur 1964; Morrison and Meslow 1983b; Willson 1974). Alterations in structure caused by logging produce changes in the organization of associated bird communities (Blake 1982; Conner and Adkisson 1975; DeByle 1981; Franzreb and Ohmart 1978; Hagar 1960; Kilgore 1971; Maurer and others 1981; Morrison and Meslow 1983a; Scott and Gottfried 1983; Strelke and Dickson 1980; Szaro and Balda 1979; Titterington and others 1979; Webb and others 1977).

Diameter-cut logging is the removal of all merchantable trees above a specified diameter breast height (d.b.h.)(Ford-Robertson 1971). This study examined relationships between breeding birds and a commercial diameter-cut in a Douglas-fir forest in west-central Idaho. The objective was to quantitatively assess the effects of the logging on breeding bird populations and community organization. All tree stems greater than 10 inches (25 cm) d.b.h. were felled within defined cutting units. Logging began in September and was completed in November 1976.

STUDY AREA

The study was made on two forested experimental watersheds in the Silver Creek drainage, a tributary of the Middle Fork of the Payette River. The area is about 56 miles (90 km) northeast of Boise in Valley County, ID. Watershed SC-6, about 403 acres (163 ha) in size, was partially logged in three separate blocks; watershed SC-3, about 319 acres (129 ha), served as an unlogged control.

Watershed slopes are steep, dissected, and face southeast. Soils are weakly developed and underlain by granitic bedrock. Annual precipitation in the area averages about 32 inches (80 cm); a large portion occurs as snowfall (Megahan and Clayton 1983).

Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and ponderosa pine (*Pinus ponderosa*) are the dominant overstory trees, with scattered stands of grand fir (*Abies grandis*), lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmannii*). Mallow ninebark (*Physocarpus malvaceous*) and white spiraea (*Spiraea betulifolia*) normally dominate the shrubby undergrowth, but Scouler willow (*Salix scouleriana*), Rocky Mountain maple (*Acer glabrum*), snowberry (*Symphoricarpos* spp.) and common chokecherry (*Prunus virginiana*) are often present. Many forbs and graminoids occupy the ground layer.

Two habitat types (Steele and others 1981) are mainly represented: Douglas-fir/ninebark, ponderosa pine phase, and Douglas-fir/white spiraea, ponderosa pine phase.

LOGGING PROCEDURE

Trees on watershed SC-6 were cut commercially to a 10-inch (25-cm) minimum diameter (breast height) in three separate and well-spaced cutting units (fig. 1). The units, topographically defined and irregularly elongate in outline, were 20, 22, and 45 acres (8, 9, and 18 ha). Uncut buffer strips bordered the cutting units, averaging 50 ft (15 m) to first- or second-order stream channels, and 100 ft (30 m) to the third-order (main) stream channel. All cutting units were on southerly aspects. Logs were yarded by helicopter to minimize site damage. Slash was lopped, scattered, and then broadcast burned. An estimated 80 percent of the slash was effectively burned.

STUDY METHODS

Two 20-acre (8-ha) study plots were established on watershed SC-6 before logging; plot 1 was located within the largest cutting unit; plot 2 was located within the smallest unit. A third 20-acre (8-ha) study plot was established on watershed SC-3 to serve as an unlogged control. Birds were censused and otherwise studied each year on all three of the study plots beginning in 1976 (prelogging) and ending in 1979 (third-year postlogging). Overstory (tree) vegetation was sampled on the cutting units before logging in 1976 and after logging in 1977. Understory vegetation (shrubs, forbs, graminoids) was sampled in 1976 (prelogging) and variously thereafter until 1981 (fifth-year postlogging).

Overstory Vegetation

Overstory vegetation data and methodology are from Geier-Hayes and Ryker (1983). A surveyed and marked 650- by 650-ft (200- by 200-m) grid system was superimposed on the experimental watersheds. Grid coordinates were used to permanently reference sampling locations. Nine sample points, each equidistant from the other, were located in each grid square. Overstory data were derived from sample points that were located within cutting unit boundaries.

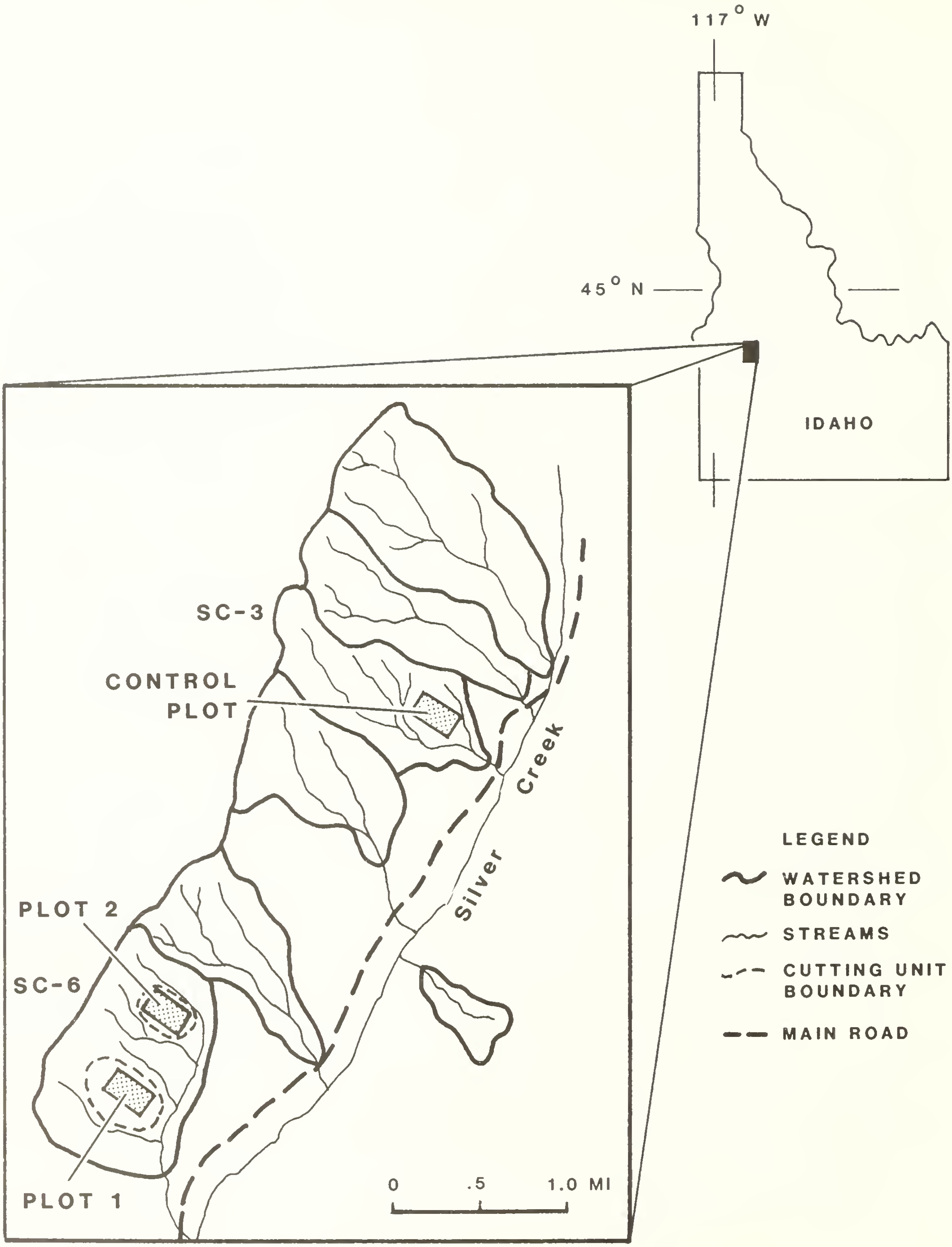

Figure 1.—Location of study plots on two small experimental watersheds of Silver Creek drainage, west-central Idaho.

From each sample point, 72.6-ft (22.1-m) lines were measured in each cardinal direction. Ten milacre (0.0004-ha) quadrats were established along each line to record tree seedling, sapling, and pole frequency and density by either height class (seedlings) or diameter class (saplings and poles). The center of a variable-radius plot was located at the midpoint of each line. Diameter (breast height), height, and other data were measured for each sample tree selected by use of an angle gauge.

Understory Vegetation

Sampling procedures followed Daubenmire and Daubenmire (1968). A 49- by 82-ft (15- by 25-m) macroplot was located at each of four sampling sites within each cutting unit. Two 82-ft (25-m) transects were placed perpendicular to the short axis of the macroplot. Forb and graminoid frequency and canopy coverage data (Daubenmire 1959) were collected from 7.87- by 19.68-inch (20- by 50-cm) microplots (50 plots) placed at 3.28-ft (1-m) intervals along the transects. Canopy coverage for each species was recorded as the midpoint of one of seven coverage classes (0-0.5, 0.5-5, 5-25, 25-50, 50-75, 75-95, and 95-100 percent).

Fifty three-dimensional plots (3.28 by 3.28 by 9.84 ft; 1 by 1 by 3 m) placed contiguous to the microplots were used to estimate shrub canopy coverage and shrub canopy volume (Zamora 1981). Shrub canopy volume for each species was recorded as the midpoint of one of eight volume classes (0-1, 1-5, 5-10, 10-25, 25-50, 50-75, 75-95, and 95-100 percent). Shrub canopy coverage classes were the same as those used for forbs and graminoids.

Breeding Birds

The 20-acre (8-ha) plots were censused for breeding birds using the Williams spot-map method (International Bird Census Committee 1970). Methodological difficulties and other special problems of the mapping method are summarized by Oelke (1981). Plots varied in shape from square to rectangular depending on terrain and cutting unit boundaries. Plots were surveyed and gridded in a Cartesian coordinate system with points flagged and numbered with stakes at 164-ft (50-m) intervals. At least 10 census visits were made annually to each plot from mid-May to late July from 1976 through 1979. Most of the work was done from sunrise to late morning when birds were most active. To ensure complete coverage, the plot was censused by walking within 82 ft (25 m) of all points on the grid. Observations extended well beyond plot boundaries.

At the end of the sampling period, concentrated groups of observations were circled as indicating areas of activity or approximate territories. Fractional parts of boundary territories were recognized. Results were converted to the number of pairs of breeding birds per 100 acres (40.5 ha).

Estimates of bird species diversity and the evenness component followed Hill (1973). Diversity was estimated as

$$N_2 = 1/\Sigma p_i^2$$

where p_i is the proportion of the collection belonging to the ith species in the sample. Species richness (N_0) was expressed as the total number of territorial species observed on a plot. Evenness was calculated using the ratio

$$E = N_2/N_1$$

where

$$N_1 = \exp(-\Sigma p_i \ln p_i).$$

Table 1.—Features of the vegetation on bird study plots before and after logging, 1976 – 78[1]

Feature	Plot 1		Plot 2	
	Prelogging	Postlogging	Prelogging	Postlogging
Basal area (ft^2/acre)	90	22	117	24
Stand volume, live tree (ft^3/acre)	3,013	43	3,407	232
Stand volume, dead tree (ft^3/acre)	61	0	192	8
Tree density (no./acre)[2]	29.3	1.9	37.5	9.8
Pole density (no./acre)[3]	96	71	101	84
Canopy coverage (percent)				
Shrubs	46.0	24.7	56.5	32.0
Forbs	26.2	22.4	23.9	21.3
Graminoids	14.9	18.0	18.6	25.9
Annuals	.02	4.76	0	3.50
Shrub canopy volume (ft^3)[4]	3.32	4.62	13.81	7.64

[1] Prelogging sampling was done in 1976; postlogging tree sampling was done in 1977; postlogging understory sampling was done in 1978. Data from Geier-Hayes and Ryker (1983).

[2] Trees >10 inches (25 cm) d.b.h.

[3] Trees <10 inches (25 cm) d.b.h.

[4] Based on plot size of 3.28 by 3.28 by 9.84 ft (1 by 1 by 3 m).

Table 2. (Con

Species	Foraging guild[1]	Nesting guild[2]	Species weight[3]	Density											
				Unlogged				Logged, plot 1[4]				Logged, plot 2[4]			
				1976	1977	1978	1979	1976	1977	1978	1979	1976	1977	1978	1979
			Grams	Pairs per 100 acres											
Hermit thrush (*Catharus guttatus*)	FFO	BTN	25.6	0	3.7	+	2.5	10.0	5.0	1.2	1.2	3.7	6.2	2.5	1.2
American robin (*Turdus migratorius*)	GGI	BTN	88.0	6.2	5.0	5.0	7.5	3.7	11.2	7.5	7.5	5.0	8.7	6.2	8.7
Solitary vireo (*Vireo solitarius*)	FGI	CDN	15.3	1.2	7.5	7.5	2.5	7.5	7.5	12.5	8.7	10.0	7.5	7.5	5.0
Warbling vireo (*Vireo gilvus*)	FGI	BTN	11.3	0	0	0	0	0	5.0	+	2.5	0	+	0	+
Nashville warbler (*Vermivora ruficapilla*)	FGI	GRN	8.3	3.7	2.5	5.0	3.7	+	5.0	2.5	3.7	3.7	3.7	2.5	2.5
Yellow-rumped warbler (*Dendroica coronata*)	FGI	CTN	13.1	13.7	12.5	5.0	2.5	12.5	6.2	7.5	5.0	8.7	6.2	7.5	10.0
Townsend's warbler (*Dendroica townsendi*)	FGI	CTN	9.0	10.0	7.5	+	+	2.5	+	0	+	+	3.7	2.5	1.2
MacGillivray's warbler (*Oporornis tolmiei*)	FGI	BTN	11.4	12.5	13.7	22.5	23.7	6.2	3.7	12.5	15.0	7.5	5.0	7.5	8.7
Western tanager (*Piranga ludoviciana*)	FGI	CTN	29.0	22.5	17.5	20.0	18.7	27.5	13.7	11.2	7.5	20.0	12.5	15.0	13.7
Black-headed grosbeak (*Pheucticus melanocephalus*)	FGI	CDN	46.0	0	+	0	+	0	3.7	+	+	0	0	0	2.5
Chipping sparrow (*Spizella passerina*)	GGG	BTN	12.2	22.5	18.7	10.0	10.0	22.5	25.0	27.5	31.2	22.5	22.5	20.0	33.7
Dark-eyed junco (*Junco hymalis*)	GGG	GRN	17.7	17.5	22.5	16.2	17.5	13.7	23.7	22.5	21.2	20.0	27.5	27.5	22.5
Cassin's finch (*Carpodacus cassinii*)	GGG	CDN	27.6	5.0	7.5	+	3.7	6.2	10.0	11.2	11.2	2.5	5.0	7.5	8.7
Pine siskin (*Carduelis pinus*)	FGG	CDN	12.1	2.5	+	2.5	3.7	2.5	1.2	3.7	3.7	3.7	+	2.5	+
Total pairs per 100 acres				214.7	212.2	202.4	203.3	194.6	205.6	200.9	209.3	189.6	187.1	172.3	195.5
Total individuals per km^2				1,074	1,061	1,012	1,016	973	1,028	1,004	1,046	948	936	862	978
Standing crop biomass (g per ha)				218	219	206	219	217	259	230	214	199	211	189	218
Species richness (N_0)				20	19	18	20	19	25	27	27	22	23	25	26
Species diversity (N_2)				12.9	13.9	11.5	12.4	13.1	15.2	14.2	13.8	14.1	13.4	13.0	12.2
Species evenness (N_2/N_1)				.87	.89	.84	.84	.86	.80	.76	.74	.84	.78	.75	.72

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[1] After Diem and Zeveloff (1980). FNI = foliage nectivore-insectivore, TDO = timber-drilling omnivore, TDI = timber-drilling insectivore, GGI = ground-gleaning insectivore, ASI = aerial sally-feeding insectivore, TGI = timber-gleaning insectivore, TGO = timber-gleaning omnivore, FGI = foliage-gleaning insectivore, FFO = foliage-feeding omnivore, GGG = ground-gleaning granivore, FGG = foliage-gleaning granivore.

[2] After Diem and Zeveloff (1980). CTN = conifer tree nester, CDN = conifer-deciduous tree nester, BTN = bush and small tree nester, RTN = rock or talus nester, SCN = secondary cavity nester, PCN = primary cavity nester, GRN = ground nester.

[3] Species weights from Salt (1957), Kilgore (1971), Ramsden and others (1979), Johnson (1965), and Behle (1943).

[4] Logging was done in late autumm 1976.

[5] + indicates that bird was observed on a plot but too infrequently to delineate a territory.

[6] Specific identification of the *Empidonax* flycatcher was not confirmed.

Breeding Birds, Logged Forest

Breeding bird density ranged from 172 to 209 pairs per 100 acres (40.5 ha) on logged study plots; 23 to 27 species were territorial (table 2). The most common species, each making up more than 5 percent of the breeding bird population, were:

chipping sparrow
dark-eyed junco
Empidonax flycatcher
western tanager

Other common species were:

Cassin's finch
MacGillivray's warbler
American robin
solitary vireo
calliope hummingbird
yellow-rumped warbler
red-breasted nuthatch
Swainson's thrush

Those 12 species accounted for 76 percent of the breeding bird community.

In standing crop biomass, the American robin was the leading species followed by the dark-eyed junco, northern flicker, western tanager, chipping sparrow, hairy woodpecker, and Cassin's finch. Those seven species made up 62 percent of the standing crop biomass in the logged forest. Total standing crop biomass on logged plots ranged from 76 to 105 grams per acre (189 to 259 grams per ha).

Hole-nesting species accounted for 16 percent of the breeding bird density on logged plots compared to the 22 percent found on unlogged plots. Most of the difference in hole-nester density resulted from reduced abundance of the red-breasted nuthatch, mountain chickadee, and brown creeper on logged areas. The hairy woodpecker, northern flicker, and white-breasted nuthatch had similar densities on both logged and unlogged plots.

Species richness was generally lowest on unlogged plots and highest on logged plots (table 2). When compared with the unlogged control plot, annual bird species richness values trended consistently upward on the logged areas. Year-to-year variation in the number of territorial species on the unlogged control plot was slight. The evenness (equitability) component of species diversity tended to decline each year in postlogging environments. No consistent annual trend in species evenness was noted on the unlogged control plot. No clear patterns were apparent between years or between logged and unlogged plots with respect to bird species diversity.

Species Responses

Although breeding bird density and standing crop biomass totals in the unlogged and logged forest were similar, there were important changes in the composition of the bird community on logged plots (table 2). Twenty-five species established territories on unlogged plots during the study; 34 species were territorial on logged plots.

Ten of the breeding bird species found in the logged forest were not present before logging; these included the house wren, mountain bluebird, western bluebird, black-backed woodpecker, yellow-bellied sapsucker, olive-sided flycatcher, warbling vireo, and black-headed grosbeak. All of the newly territorial species attracted to logged areas occurred in low densities. Among the species that were territorial in the unlogged forest, only the golden-crowned kinglet was absent from logged study plots.

In addition to those species attracted to logged plots, several others appeared to react positively to structural changes in the vegetation caused by timber cutting. Species with higher densities after logging included the *Empidonax* flycatcher, Townsend's solitaire, American robin, chipping sparrow, dark-eyed junco, and Cassin's finch. Of these, only the Cassin's finch nested in the overstory; the others nested either on the ground or in the understory layer (Medin 1985). Each of the six species or genera have been classified by Thomas (1979) as having medium or high versatility ratings with respect to reproductive and feeding orientation. All but the *Empidonax* flycatcher are characteristic of ecotonal habitats. The American robin, chipping sparrow, dark-eyed junco, Cassin's finch, and *Empidonax* flycatcher are widespread breeding species in the coniferous forests of central Idaho.

Seven species responded negatively to the logging. These were:

mountain chickadee
red-breasted nuthatch
brown creeper
Swainson's thrush
Townsend's warbler
MacGillivray's warbler
western tanager

Three species—the mountain chickadee, red-breasted nuthatch, and brown creeper—are secondary cavity nesters. All but the MacGillivray's warbler are found in old-growth habitats (Thomas 1979). The brown creeper nests under loose bark and is often associated with mature stands of ponderosa pine. The Townsend's warbler is a species characteristic of multiple canopy, mature, and old-growth true fir and mixed conifer stands.

Densities of other breeding bird species listed in table 2 were similar on both logged and unlogged plots. The most numerous of these included the calliope hummingbird, hairy woodpecker, northern flicker, hermit thrush, solitary vireo, Nashville warbler, yellow-rumped warbler, and pine siskin. Incongruently, three of these species—the hairy woodpecker, hermit thrush, and Nashville warbler—were given low versatility scores by Thomas (1979).

Five woodpecker species (yellow-bellied sapsucker, hairy woodpecker, white-headed woodpecker, black-backed woodpecker, and northern flicker) were territorial on one or both of the logged plots during the study (table 2). Although there were few snag trees remaining immediately after logging, the slash-burning treatment conducted weeks later killed or damaged many of the residual unmerchantable trees. The highest woodpecker densities recorded during the study were on logged plots the year following logging and slash burning. Some, but not all, of the territorial woodpeckers nested directly on the logged plots. Hagar (1960) also noted increased woodpecker densities on recently logged areas in northwestern California.

The presence of relatively high numbers of woodpeckers on logged plots resulted in a number of holes being excavated in dead or weakened residual trees which, in turn, provided nest sites for the western bluebird, mountain bluebird, and house wren. Frequent and prolonged combative encounters between wrens and bluebirds near excavated or natural tree cavities suggested competition for nest sites on logged plots. Recently dead and trunk-blackened trees, particularly Douglas-fir, were used heavily by the black-backed woodpecker for feeding and, in two cases, for nest sites. The pileated woodpecker, an uncommon bird in the area, was rarely observed on logged plots.

Table 3 summarizes responses of common bird species to tree removal treatments in coniferous forests of the western United States. The notations in table 3 represent a liberal interpretation of published information that was often originally presented in tabular form. Source material is arrayed left to right roughly on the basis of the degree of tree removal with the most severe treatment on the extreme right. Twelve species tended to react positively to most tree removal treatments. These were:

olive-sided flycatcher
rock wren
house wren
winter wren
western bluebird
mountain bluebird
American robin
rufous-sided towhee
chipping sparrow
fox sparrow
dark-eyed junco
Cassin's finch

The wrens, bluebirds, and sparrows were consistent in showing an upward numerical response. Nine species responded negatively to most treatments. These were:

western flycatcher
mountain chickadee
red-breasted nuthatch
pygmy nuthatch
brown creeper
golden-crowned kinglet
hermit thrush
Townsend's warbler
red-faced warbler

Responses of other species listed in table 3 are less clear. The hairy woodpecker, northern flicker, Townsend's solitaire, yellow-rumped warbler, and pine siskin either responded minimally or were inconsistent in their response to treatment except for the highest levels of tree removal. In general, the numerical response of many species depends on the degree of tree removal; compare, for example, species responses listed from Kilgore (1971) with those from the clearcut treatment of Szaro and Balda (1979).

Guild Responses

Birds may be placed in categories, or guilds, based on foraging behavior or the type of substrate in which foraging occurs (Diem and Zeveloff 1980; Root 1967). The 35 breeding bird species listed in table 2 were divided into five foraging guilds: foliage foragers, flycatchers, timber drillers, timber gleaners, and ground foragers (table 4).

Birds that forage by searching foliage (foliage foragers) formed the largest single category, and these, along with the ground foragers, made up the largest proportion of all foraging categories. Among the foliage foragers, insectivorous species predominated. The ground-foraging forms, which included chipping sparrows, dark-eyed juncos, and Cassin's finches, were largely granivorous. The flycatchers were the olive-sided flycatcher and the *Empidonax* flycatcher. Four species—the yellow-bellied sapsucker, hairy woodpecker, white-headed woodpecker, and black-backed woodpecker—were classified as timber drillers, and three species—the red-breasted nuthatch, white-breasted nuthatch, and brown creeper—were grouped as timber gleaners.

Foliage foragers (17 species) had the highest total density of all foraging guilds in the unlogged forest (table 4). The three species with the highest densities were the Swainson's thrush, western tanager, and mountain chickadee. The foliage foraging guild declined after logging. One species, the golden-crowned kinglet, was territorial only on unlogged plots. Three foliage foragers (house wren, warbling vireo, and black-headed grosbeak) were territorial only on logged plots.

Birds that forage by gleaning the surface of bark (timber gleaners) declined the most after logging; guild density in the third year following logging was only about one-third that of prelogging density. The numerical decrease was most severe for the brown creeper and red-breasted nuthatch. Other foraging guilds—the ground foragers and flycatchers—were more numerous on logged plots. Birds that feed on the ground were, by a slight margin, the most abundant foraging guild on logged plots 3 years after logging. Each of the nine species in the ground-foraging guild was proportionately more abundant in logged environments than in the unlogged forest. The timber-drilling guild maintained relatively stable total densities on both logged and unlogged plots.

Categorizing birds on the basis of the substrate in which nesting occurs provides additional information about the breeding bird community. Six nesting guilds were recognized: conifer tree, conifer-deciduous tree,

Table 3.—Responses of common bird species to tree removal in western coniferous forests. Upward-pointing arrows (↑) indicate a positive numerical response; downward-pointing arrows (↓) indicate a negative numerical response; horizontal arrows (→) indicate a minimal numerical response

	Source, treatment, and location									
Species	Kilgore (1971) Understory fuel reduction CA	Mannan and Meslow (1984) Thinning OR	Szaro and Balda (1979) Shelterwood AZ	Scott and Gottfried (1983) Various AZ	Scott and others (1982) Patch clearcut CO	This study Diameter cut ID	Franzreb and Ohmart (1978) Selection AZ	Hagar (1960) Clearcut CA	Blake (1982) Clearcut AZ	Szaro and Balda (1979) Clearcut AZ
Broad-tailed hummingbird (*Selasphorus platycercus*)			↑				→		↑	↓
Yellow-bellied sapsucker	→	→				↑	↑	→	↓	
Williamson's sapsucker		↓		↓	→		→			
Hairy woodpecker	→	→	↑	↓	↑	→	→	↑	→	↓
White-headed woodpecker	→	→				→		→		
Black-backed woodpecker		→				↑				
Northern flicker	→	→	→	→	→	→	→	↑	↑	↓
Olive-sided flycatcher	→				↑	↑	↑	↑		
Western flycatcher (*Empidonax difficilus*)			↓	↓	→		↓	↓		↓
Steller's jay	→	→	↓	↓			→	↑	↑	↓
Mountain chickadee	→	→	→	→	↓	↓	↓	↓	↓	↓
Red-breasted nuthatch	→	↓		↑	↓	↓	↓	↓		
White-breasted nuthatch		→	↑	→		→	↓		→	↓
Pygmy nuthatch (*Sitta pygmaea*)			↓	→			↓		↓	↓
Brown creeper	→	↓		↓		↓	↓	↓	↓	
Rock wren			↑			↑				↑
House wren			↑	↑		↑	↑	↑	↑	
Winter wren	→					↑		↑		
Golden-crowned kinglet	→	↓			↓	↓	↓	↓		
Ruby-crowned kinglet		↑		↓	↓	→	↓		↓	
Western bluebird			↑			↑	↑		↑	↓
Mountain bluebird						↑	↑			↑
Townsend's solitaire	→	→			→	↑	→			
Swainson's thrush		↓				↓				
Hermit thrush	↓	↓	↓	↓	→	→	↓	↓		↓
American robin	↑	→	↑	↑		↑	↑	↑		↑
Solitary vireo	→	↑	↑			→		→		↓
Warbling vireo	→			→		↑	↑			
Yellow-rumped warbler	→	→	↑	→	→	→	↓	↑	→	↓
Townsend's warbler		↓				↓			↓	
Grace's warbler (*Dendroica graciae*)			↑				↓			↓
MacGillivray's warbler		↓				↓		↑		
Red-faced warbler (*Cardellina rubrifrons*)			↓	→			↓			↓
Western tanager	→	→	↑	→		↓	↑	↑		↓
Black-headed grosbeak	→		↓			↑	→	↑		↓
Rufous-sided towhee (*Pipilo erythrophthalmus*)	↓							↑	↑	↑
Chipping sparrow		↑	↑			↑	→		↑	↓
Fox sparrow (*Passerella iliaca*)								↑	↑	
Dark-eyed junco	→	↑	→	→	↑	↑	↑	↑	↑	↓
Cassin's finch		↑				↑			↑	
Pine siskin		→		↑		→	→	↑	→	

Table 4.—Guild structure on logged and unlogged bird study plots, 1976–79

Guild	No. species	Density							
		Unlogged				Logged[1]			
		1976	1977	1978	1979	1976	1977	1978	1979
		Pairs per 100 acres							
Foraging guild									
Foliage foragers	17	121.0	109.8	121.2	103.5	103.5	80.9	73.6	78.4
Flycatchers	2	20.0	20.0	17.5	16.2	13.8	23.1	23.8	29.3
Timber drillers	4	2.5	5.0	2.5	5.0	5.6	8.7	7.5	5.6
Timber gleaners	3	17.5	21.2	27.5	37.4	18.7	9.4	8.8	6.8
Ground foragers	9	53.7	56.2	33.7	41.2	50.6	74.3	73.0	82.3
Nesting guild									
Conifer tree	6	49.9	37.5	27.5	23.7	37.4	24.2	23.7	23.7
Conifer-deciduous tree	6	39.9	41.2	48.7	43.6	33.6	34.2	35.6	34.2
Bush and small tree	7	68.7	66.1	62.5	67.4	61.2	74.8	73.0	91.6
Primary cavity	6	5.0	7.5	5.0	7.5	10.0	11.2	11.2	8.7
Secondary cavity	6	35.0	39.9	42.5	47.5	31.8	26.2	15.6	23.0
Ground	5	22.4	25.0	21.2	21.2	22.4	35.6	34.3	29.3

[1] Average of bird study plots 1 and 2. Logging was done in late autumn 1976.

bush and small tree, primary cavity, secondary cavity, and ground (table 4). Bush and small-tree nesters (seven species) had the highest total density of all nesting guilds in the unlogged forest. This nesting guild reacted positively to logging. The American robin, *Empidonax* flycatcher, and the chipping sparrow increased most in postlogging environments; the warbling vireo was found only on logged plots.

Species that nest on the ground increased after logging. Each of the ground-nesting species represented in the study made up a greater proportion of the breeding bird population in logged areas than in the unlogged forest. The dark-eyed junco accounted for over 70 percent of the total density of the ground-nesting guild in both the logged and unlogged forest. The rock wren and winter wren were territorial only on logged plots.

The nesting guild with the largest numerical decrease in response to logging was the secondary cavity nesters, which dropped from almost 19 percent of the total breeding bird density in the unlogged forest to about 10 percent in the logged forest. Most of the decrease resulted from reductions in the abundance of the red-breasted nuthatch, mountain chickadee, and brown creeper. Although occurring in low densities, three secondary cavity nesters (house wren, western bluebird, and mountain bluebird) were found only on logged plots. Of the six secondary-cavity nesting species found during the study, three species—those that were most abundant—responded negatively to logging, and three species—those not represented in the unlogged forest—responded positively to logging.

SUMMARY AND CONCLUSIONS

These data suggest that separate components of the breeding bird community, including species populations and both foraging and nesting guilds, responded differently to structural changes in the forest vegetation caused by diameter-cut logging. Although there were slight changes in total density and standing crop biomass during the 3-year postlogging period, greater changes occurred in the species composition of the breeding bird population. Logging resulted in a positive response by six species:

Empidonax flycatcher
Townsend's solitaire
American robin
chipping sparrow
dark-eyed junco
Cassin's finch

Species responding negatively were:

mountain chickadee
red-breasted nuthatch
brown creeper
golden-crowned kinglet
Swainson's thrush
Townsend's warbler
western tanager

Densities of eight species remained relatively stable on both logged and unlogged plots:

calliope hummingbird
hairy woodpecker
northern flicker
ruby-crowned kinglet
hermit thrush
solitary vireo
Nashville warbler
pine siskin

Bird species richness was consistently higher on logged plots than on unlogged plots and trended upward each year after logging. Ten breeding bird species were territorial only in the logged forest:

yellow-bellied sapsucker
black-backed woodpecker
olive-sided flycatcher
rock wren
house wren
winter wren
western bluebird
mountain bluebird
warbling vireo
black-headed grosbeak

All but the winter wren are characteristic of ecotonal habitats. Of those species that were territorial in the unlogged forest, only the golden-crowned kinglet was not found as a breeding bird on logged plots. There were no clear patterns in bird species diversity values either between years or between logged and unlogged plots. The evenness (equitability) component of bird species diversity tended to decline each year in postlogging environments.

Categorizing birds according to foraging or nesting behavior, or by the substrate in which foraging or nesting occurs, suggests how entire groups of species (guilds) may respond to habitat alterations. Among five recognized foraging guilds, two—the foliage foragers and the timber gleaners—were less numerous on logged plots. The timber gleaners, proportionately the most severely affected guild, dropped to about one-third prelogging densities in the third year following logging. Low timber-gleaning guild densities on logged plots were probably caused by the removal of larger trees. Other guilds—the ground foragers and the flycatchers—were more numerous on logged plots. Of nine species represented in the ground-foraging guild, each was proportionately more abundant in the logged forest than in the unlogged forest. The most abundant species among the ground foragers (chipping sparrow, dark-eyed junco, Cassin's finch) were granivores. Timber-drilling species, at least in total, were a relatively stable component of the breeding bird community on both logged and unlogged plots.

Wiens (1978) noted that foliage-feeding forms numerically dominate the avifauna in North American coniferous forests, with ground-feeding, timber-foraging, and aerial feeders less important, in decreasing order. The birds of the coniferous forest we studied in west-central Idaho appear to generally fit this pattern.

Birds that nest in bushes and small trees, represented by seven species, formed the most abundant nesting guild in both the logged and unlogged forest. Bush and small-tree nesters, and those species that nest on the ground, had higher densities on logged plots. Ground-nesting species, the most numerous of which was the granivorous dark-eyed junco, showed the largest increases in density. The secondary cavity-nesting guild, made up mostly of the mountain chickadee, red-breasted nuthatch, and brown creeper, decreased on logged plots. Secondary cavity nesters may have declined partly because of the lack of snag trees remaining after logging. Three secondary cavity-nesting species—the house wren, western bluebird, and mountain bluebird—were found as breeding birds only on logged plots. Total density of the primary cavity-nesting guild changed little in the logged forest.

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☆U.S. GOVERNMENT PRINTING OFFICE 1985-0-676-039/20,028

Medin, Dean E. Breeding bird responses to diameter-cut logging in west-central Idaho. Research Paper INT-355. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 12 p.

Responses of breeding bird populations to structural changes in a Douglas-fir forest caused by logging are quantitatively described. Density, diversity, standing crop biomass, foraging and nesting guild composition, and other attributes of the breeding bird community were assessed on logged and unlogged plots.

KEYWORDS: *Pseudotsuga menziesii*, diameter-cut logging, helicopter logging, density, diversity

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Research Paper
INT-356

January 1986

Ecological Genetics of *Pinus contorta* in the Upper Snake River Basin of Eastern Idaho and Wyoming

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CLEMSON UNIVERSITY
FEB 25 1986
PUBLIC DOCUMENTS

THE AUTHOR

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RESEARCH SUMMARY

Genetic differentiation of 60 populations of *Pinus contorta* primarily from eastern Idaho and adjacent Wyoming was assessed in three studies involving (1) growth and development in field environments, (2) the periodicity of shoot elongation in the greenhouse, and (3) freezing tolerance in the laboratory. Genetic differentiation between populations was observed for traits that included 3-year height, leaf length, freezing tolerance, and the pattern of shoot elongation. Regression models related as much as 83 percent of the variation between populations to the elevation and geographic location of the seed origin. Elevational clines were particularly steep. Consequently, if maladaptation is to be controlled in artificial reforestation, seed transfer should be restricted severely for elevation but geographically may be relatively liberal. Detailed practical guidelines will be presented separately.

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INTRODUCTION

Ecological genetics is devoted to exploring the ecological bases for adaptive differentiation between populations. In lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), differentiation of populations from both Canada (Lindgren and others 1980; Hagner 1980; Ying and others 1985) and the United States (Rehfeldt 1985b) is related to the geographic origin and elevation of the seed source. Adaptive clines, however, reflect environmental gradients. As a result, clines in British Columbia reflect the relatively gentle environmental gradients associated with a region of dissected plateaus. But in the rugged Rocky Mountains of the United States, adaptive clines tend to be steep for a variety of traits that include growth potential, morphology, and cold hardiness (Rehfeldt 1980, 1983), patterns of shoot elongation (Rehfeldt and Wykoff 1981; Stoneman 1985; Rehfeldt 1985a), and resistance to insects and diseases (Hoff 1985). Regardless of geographic region, populations appear as physiological specialists for relatively small segments of the environmental gradient.

Steep adaptive clines have direct relevance to forest management. Artificial reforestation carries the implicit goal of maximizing productivity while maintaining adaptedness. Steep clines require that seed for reforestation be transferred only short distances along the environmental gradient if maladaptation and resultant losses in productivity are to be controlled.

The present study is part of a series that (1) examines adaptive variation between lodgepole pine populations, (2) relates patterns of variation to geography, topography, physiography, and climate, and (3) develops seed transfer guidelines for reforestation.

MATERIALS AND METHODS

The study of population differentiation included seedlings from 60 populations, 51 of which represented the geographic distribution and ecologic amplitude of the species in the upper Snake River Basin (fig. 1). Additional populations from peripheral areas provided a link to other studies in this series: four were from the Wasatch Mountains of Utah and southeastern Idaho;

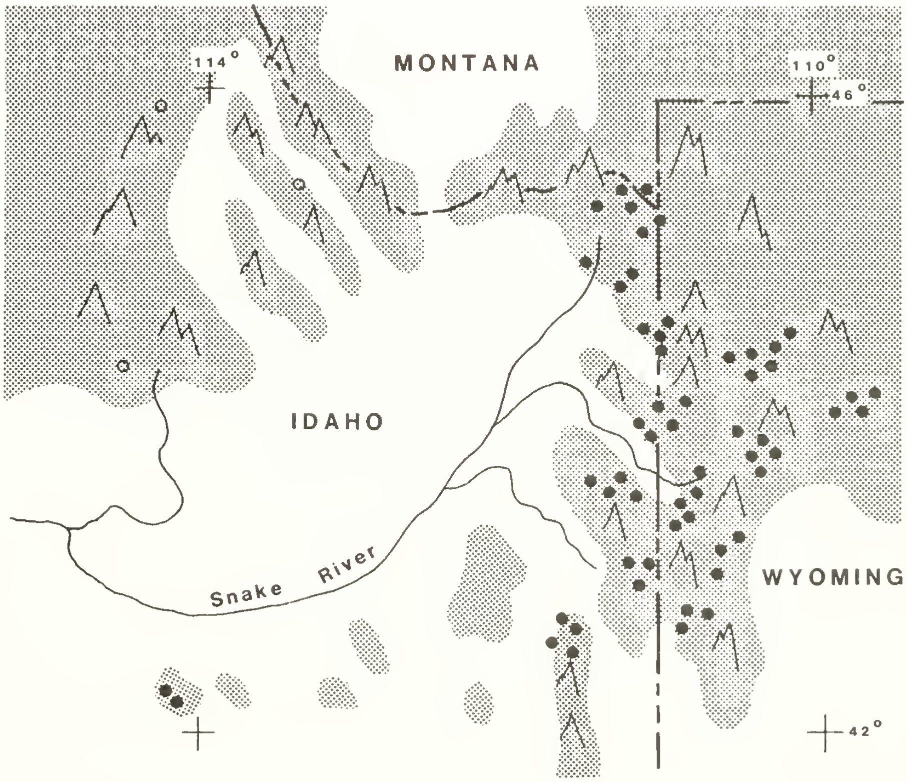


Figure 1.—Geographic distribution of Pinus contorta *(shading according to Little 1971) within the region of study and location of populations.*

three were from the lower Snake River basin of central Idaho; and two were from a small disjunct population from Deadline Ridge in south-central Idaho (fig. 1). Seedlings from the 60 populations were used in separate studies of (1) growth and development in field environments, (2) periodicity of shoot elongation in a greenhouse, and (3) cold hardiness in the laboratory. Because cone collections, experimental procedures, and statistical analyses are detailed in the first paper of this series, which involved populations from the Wasatch and Uinta Mountains of Utah (Rehfeldt 1985a), only an outline of these procedures follows.

Growth and Development

One set of seedlings from each of the 60 populations grew for 6 months in plastic containers (10 in^3) in a shadehouse at Moscow, ID (lat. 48.5° N., long. 116.7° W.). In the fall, seedlings were transplanted into two environments, 2,200 and 5,000 feet elevation, at the Priest River Experimental Forest, 150 miles north of Moscow. Eight seedlings, spaced at 1.0 foot and 0.5 foot at low and high elevation sites, respectively, were planted in row plots, separated by 1.5 feet and 1.0 foot at the respective sites. Three blocks were established at each site, and both plantings were maintained under intensive culture.

The performance of each seedling was described by four variables for which differentiation of Utah populations had been pronounced: (1) height—seedling height after 3 years; (2) late growth—amount of the 3-year predetermined shoot that elongated after the fourth week of elongation in the respective environments; (3) leaf length—the length of a leaf near the center of the 3-year shoot; and (4) adjusted height—3-year height adjusted by regression on 2-year height. By representing the increment from a common 2-year height, adjusted height is relatively independent of previous environmental (such as transplanting shock) and genetic effects and thereby is capable of reflecting adaptation of populations to a particular environment for a single growing season.

In addition, scores were made for the presence or absence of injury from a freeze (16 °F) that occurred in mid-May at the low-elevation site. Injuries ranged from death of the developing shoot to reductions in internode lengths near the shoot tip.

To account for heterogeneous variances at the two test environments, data were transformed to standard normal deviates (Steel and Torrie 1960) for each test site and the deviates were analyzed according to a model of random effects. The model estimated: (1) main effects for test environments, blocks within environments, and populations; (2) the interaction of populations × environments; (3) an experimental error, composed of the interaction of populations × blocks within environments; and (4) a residual error. As a result of the transformations, mean squares associated with the main effects of test environments were zero. A harmonic mean of 7.20 reflected the number of seedlings representing each population in each block.

Injury from the spring frost was analyzed according to a model of random effects, which estimated main effects for blocks and populations, plus an error.

Periodicity of Shoot Elongation

Another set of seedlings grew for 1 year in plastic containers (45 in^3) in a shadehouse at Moscow. Nine seedlings from each population grew in each of three blocks. In early March of the second growing season, seedlings were moved into a greenhouse before shoot elongation had begun. Greenhouses were maintained under natural lighting; temperatures were about 75 °F during the day and 55 °F at night. All seedlings were measured three times each week until elongation of the preformed bud had ceased.

As described by Rehfeldt and Wykoff (1981), shoot elongation of individual trees was expressed mathematically by a logistic function that included a hyperbolic time term. Regression statistics allowed calculation of the following variables for describing periodicity of shoot elongation of individual seedlings: (1) initiation of growth—the day on which 0.1 inch of cumulative growth had occurred; (2) cessation of growth—the day on which all but 0.1 inch of growth had occurred; (3) duration of growth—the number of days between initiation and cessation; (4) rate of growth—elongation per day during the period of maximum elongation; and (5) total elongation.

Population differentiation was assessed according to least squares analyses of random effects that estimated main effects for populations and blocks, the interaction of populations × blocks, and an error. A harmonic mean of 8.81 reflected the number of seedlings representing each population in each block.

Cold Hardiness

To estimate the relative cold hardiness of populations in early autumn, laboratory tests of freezing tolerance were made according to the general procedures of Levitt (1972). Mature leaves were collected in late September from near the center of the 3-year shoot of trees planted at 5,000 feet elevation in the study of growth and development.

Four sets of eight leaves were collected from each eight-tree plot; each set contained one leaf from each tree. One set of leaves from each plot was exposed to one of four test temperatures (−4 °F, −6 °F, −10 °F, and −12 °F) by cooling at the rate of 10 °F/h. Injured leaves were identified visually by the presence of discolored and flaccid tissue (Rehfeldt 1980). Population differentiation for the proportion of injured leaves from each plot was assessed from a model of random effects that allowed estimation of main effects for populations, blocks, and test temperatures; three two-way interactions; and a residual.

Patterns of Variation

Geographic patterns of genetic variation were assessed from a series of regression analyses that fit independent variables describing the origin of populations to the array of population means. Because the primary purpose of these analyses was to describe genetic patterns of variation for the upper Snake River Basin, regression analyses considered only the 51 representative populations. The sequence of regression analyses concentrated first on the relationship between performance and elevation of the seed source, and second on geographic patterns of variation that were independent of elevation. Adequacy of a model was judged according to the goodness of fit (R^2), residual variance ($s_{y \cdot x}$), and geographic or ecologic patterns displayed by residuals (Draper and Smith 1966).

Elevational models considered both a linear and quadratic relationship between performance and elevation of the seed source. Deviations from the best fitting elevational regressions were then used as dependent variables for considering geographic patterns of variation that were independent of elevation. The geographic model included four independent variables, plus their squares: latitude, longitude, northwest departure, and northeast departure. The latter two variables were obtained by rotating the grid of latitude and longitude by 45°. Thus, eight independent variables were included in the model, which was fit with a stepwise regression program for maximizing R^2 (Barr and others 1979). Finally, for those variables in which both the elevational and geographic models had been significant, elevation of the seed source was added to the independent variables of the best fitting geographic model in order to estimate the joint determination of performance by geography and elevation.

RESULTS

Because each study was autonomous, the results of each are presented separately but are considered jointly in establishing patterns of genetic variation.

Growth and Development

The effects of planting environment on growth and development of seedlings were pronounced for all traits (table 1). Compared to trees growing at high elevation, trees at low elevation were much taller and had longer leaves. In addition, late growth, defined as the proportion of the predetermined shoot that elongated after the fourth week, was measured approximately 5 weeks earlier at low elevation than at high and therefore was affected tremendously by the environment. Adjusted heights show that even if all trees had been the same height at age 2, those growing at low elevation would still have been tallest after 3 years.

For nearly all variables, the range in population mean values was considerably different at the two planting environments (table 1). For these ranges to differ greatly illustrates the heterogeneous variances that required adjustment before statistical analyses were made.

By accounting for more than 20 percent of the total variance, effects of populations were pronounced for 3-year height and injury from a spring frost (table 2). These strong effects are illustrated by mean differences between populations of as much as 0.8 foot in height and 50 percent in trees injured by frost. On the average, trees damaged by frost were 3.2 inches shorter after 3 years than uninjured trees from the same population. Relatively weak effects for late growth are likely due to the relatively late stage of elongation at which measurements were begun: the average tree produced only 10 percent of the 3-year shoot as late growth. Consequently,

Table 1.—Mean values according to test environment and range of population means in each environment

Variable		Mean values		Range in population means	
		2,200 ft	1,500 ft	2,200 ft	5,000 ft
Late growth	(inches)	1.1	0.7	0.8	0.4
Leaf length	(inches)	2.9	2.7	1.1	0.8
Height	(inches)	17.1	13.9	12.2	5.8
Adjusted height	(inches)	16.2	14.7	5.7	1.8
Frost injury	(percent)	22	—	56	—

Table 2.—Results of analyses of variance for growth and development presented as intraclass correlations, the ratio of individual variance components to the sum of all components

Source of variance	Variable				
	Late growth	Leaf length	Height	Adjusted height	Frost injury
Environments	0	0	0	0	0
Blocks in environment	0.03**	0	0.02**	0	0
Populations	.06**	0.08**	.36**	0.02*	0.20**
Environment × population	0	.02	.01	.09**	—
Experimental error	.07**	.07	.03**	.04**	.79
Within plots	.84	.83	.57	.84	—

*Statistical significance of the F-value at the 5 percent level of probability.
**Statistical significance of the F-value at the 1 percent level of probability.

mean values for populations ranged from only 0.7 to 1.2 inches. Significant effects of populations in leaf length reflected mean differences as large as 0.8 inch. And finally, the significant effects of populations for adjusted height show that populations would have differed in 3-year height even if all trees had been the same height at age 2, even though 2-year height accounted for 64 percent of the variance in 3-year height of individual trees.

Significant interactions of populations and environments were detected only for adjusted height; consequently, main effects for this variable were significant with a rather low level of probability (table 2). The interaction was caused by (1) a lack of differences between populations in the environment at high elevation, combined with (2) statistically detectable differences at low elevation. Consequently, subsequent analyses for adjusted height use only those data from the low-elevation site.

Periodicity of Shoot Elongation

The logistic function described periodicity of shoot elongation of individual trees nearly perfectly. Values of R^2 ranged from 0.94 to essentially 1.0 while averaging 0.99. Analyses of variance detected strong effects of populations for duration, rate, cessation, and amount of shoot elongation (table 3). These effects accounted for 21 to 38 percent of the total variance and are illustrated in figure 2. Differences between populations were as large as 15 days in cessation, 16 days in duration, 0.1 inch/day in rate, and 3.4 inches in the amount of elongation. Populations differed by only 0.8 day in the initiation of shoot elongation, and, consequently, no differences could be detected statistically.

Cold Hardiness

Effects of test temperatures dominated analyses of variance (table 4). These effects are associated with a range in injury from 36 percent at −4 °F to 78 percent at −12 °F. Effects of populations were significant but accounted for only 5 percent of the total variance. Mean differences between populations amounted to as much as 55 percent injury.

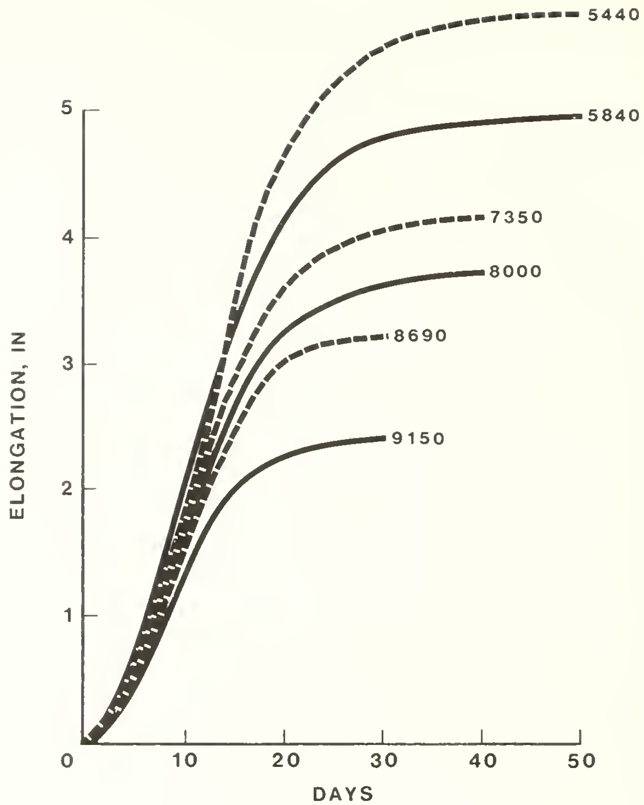


Figure 2.—Periodicity of shoot elongation for populations from a range of elevations (feet) that represented maximum differences in response.

Patterns of Variation

Elevation of the seed source had a pronounced effect on population performance (table 5, fig. 3). Elevational models accounted for more than 70 percent of the variance between populations for five variables and were statistically significant for all variables except the initiation of shoot elongation. As elevation increases, growth potential decreases, largely because of an associated decline in late growth and in the rate, duration, and cessation of shoot elongation. Leaf lengths also decline with

Table 3.—Results of analyses of variance for periodicity of shoot elongation presented as intraclass correlations, the ratio of a variance component to the sum of all components

Source of variance	Initiation	Duration	Rate	Cessation	Elongation
Blocks	0.10**	0.04**	0.03**	0	0.01
Populations	.02	.22**	.21**	0.23**	.38**
Interaction	.15**	0	.06	0	.03*
Within plots	.73	.73	.70	.77	.58

*Statistical significance of the F-value at the 5 percent level.
**Statistical significance of the F-value at the 1 percent level.

Table 4.—Results of analyses of variance of freezing tests presented as intraclass correlations, the ratio of a variance component to the sum of all components

Source of variance	Intraclass correlation
Blocks	0.06*
Temperatures	.21**
Populations	.05**
Populations × temperatures	0
Residual[1]	.68

*Statistical significance of the F-value at the 5 percent level.
**Statistical significance of the F-value at the 1 percent level.
[1] Composed of the interactions involving blocks.

Table 5.—Coefficients of determination (R^2) for regression analyses relating genetic variation to geographic and physiographic variables

Variable	Elevational model		Geographic model	Combined model
	Linear	Quadratic		
Growth and development				
Late growth	0.26**	0.27**	0.04	—
Leaf length	.32**	.32**	.26*	0.49**
Height	.70**	.70**	.24*	.78**
Adjusted height (2,200 ft)	.50**	.53**	.31**	.66**
Frost injury	.21**	.22	0	—
Periodicity of shoot elongation				
Duration	.71**	.74**	.31**	.83**
Rate	.74**	.74**	.09	—
Cessation	.70**	.74**	.29*	.80**
Elongation	.78**	.79**	.19	—
Cold hardiness				
Injury	.13**	.13*	.33**	.43**

*Statistical significance at the 5 percent level of probability.
**Statistical significance at the 1 percent level of probability.

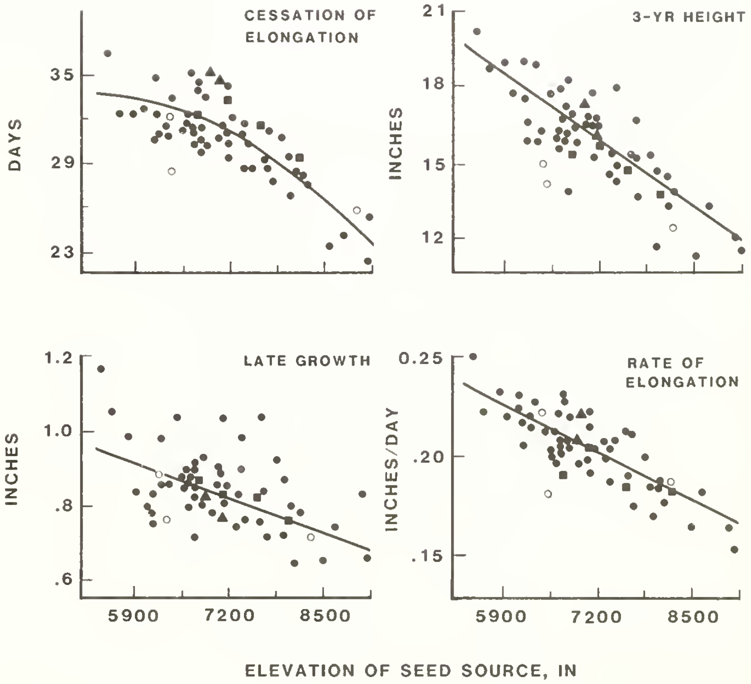


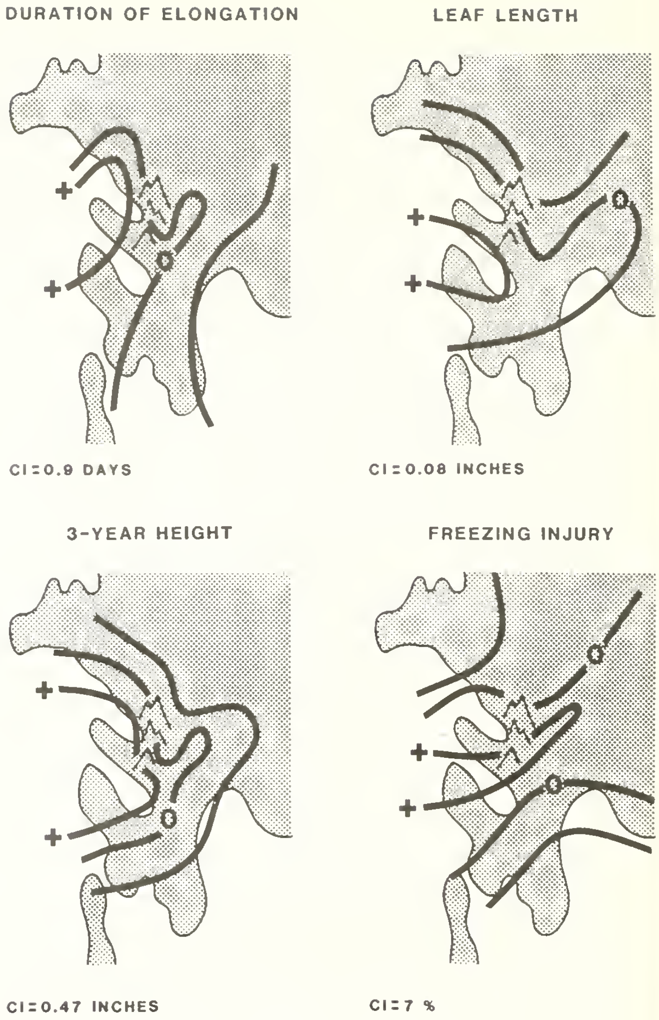
Figure 3.—Population means for four variables plotted by elevation of the seed source. Symbols code geographic origins: ● = Upper Snake River Basin; ○ = Lower Snake River, ■ = Wasatch Mountains, ▲ = Deadline Ridge.

increasing elevation of the seed source, but freezing tolerance increases. The strong relationship between elevation and adjusted height indicates that, at the low elevational planting, populations from mild environments still would have been tallest even if all trees had been the same height at age 2. Quadratic models provided a significant reduction in the residual mean square of the linear model for only the cessation and duration of elongation.

The geographic model (table 5) was statistically significant for only half of the variables. At most, this model accounted for less than a third of the variance in the dependent variables that was not explained by elevation. Consequently, geography accounted for less than 25 percent of the variance among populations. Thus, elevational clines tend to be steep, and geographic clines are relatively gentle. Nevertheless, geographic variables plus elevation (the combined model) accounted for 43 to 83 percent of the variance of populations.

Geographic patterns of genetic variation that are independent of elevation are presented in figure 4 for several traits. These patterns were generated from values predicted by the geographic model. The contour interval is scaled to a value equaling half the least significant difference (Steel and Torrie 1960) between populations at the 80 percent level of probability [½ *lsd*(0.2)]. Because values of *lsd* were calculated from the analysis of variance (table 2), contours represent about half the geographical distance associated with population differentiation at the 80 percent level of probability. Contouring was begun with the overall mean, the zero deviation from the elevational regression.

All variables for which the geographic model was significant presented similar patterns of genetic variation. Those variables selected for figure 4 illustrate patterns of greatest divergence. In general, populations in the west-central regions are of highest growth potential and lowest hardiness. From this area, growth potential decreases and hardiness increases in all directions. The general pattern, however, is influenced greatly by the rugged Teton Range. Populations of relatively high growth potential and low hardiness extend into the


DURATION OF ELONGATION

LEAF LENGTH

CI=0.9 DAYS

CI=0.08 INCHES

3-YEAR HEIGHT

FREEZING INJURY

CI=0.47 INCHES

CI=7 %

Figure 4.—Geographic patterns of variation that are independent of elevation. Shading marks the distribution of lodgepole pine in reference to the Teton Range. C.I. = the contour interval, which is scaled to a value of ½ lsd*(0.2). The zero contour represents the mean of all populations standardized for elevation.*

Table 6.—Correlation matrix relating population means for all studies[1]

Variable	Code	LL	H	AH	FI	I	D	R	C	EL	IN
Growth and development											
Late growth	LG	0.56	0.68	0.61	0.34	-0.24	0.54	0.61	0.53	0.61	0.13
Leaf length	LL		.62	.53	.33	-.27	.62	.59	.62	.64	.21
Height	H			.81	.56	-.21	.84	.87	.85	.90	.36
Adjusted height (2,200 ft)	AH				.44	-.32	.71	.71	.70	.75	.20
Frost injury	FI					.08	.42	.43	.43	.44	.27
Periodicity of shoot elongation											
Initiation	I						-.33	-.23	-.27	-.31	.10
Duration	D							.84	.99	.93	.27
Rate	R								.84	.97	.40
Cessation	C									.93	.28
Elongation	EL										.37
Cold hardiness											
Injury	IN										

[1] Coefficients of absolute value >0.27 are statistically significant at the 5 percent level.

Table 7.—Average difference between the observed performance of peripheral populations and that expected from the elevational regressions

Variable		Lower Snake River	Wasatch Mountain	Deadline Ridge
Growth and development				
Late growth	(inches)	−0.07	−0.00	−0.07
Leaf length	(inches)	−.08	.05	.13
Height	(inches)	−2.48	−.71	.57
Adjusted height	(inches)	−.41	−.86	1.27
Frost injury	(percent)	−9.3	−8.7	−3.0
Periodicity of shoot elongation				
Initiation	(days)	0	−.1	.3
Duration	(days)	−1.9	1.6	3.3
Rate	(inches/days)	−.01	−.01	.01
Cessation	(days)	−1.8	1.6	3.6
Elongation	(inches)	−.35	−.02	.58
Cold hardiness				
Injury	(percent)	−3.1	−1.6	5.1

drainages east of the Tetons. Significant intercorrelations between variables (table 6) produce the similar elevational and geographic clines. Particularly noteworthy are the correlations among variables associated with growth potential. Whether measured in the field or greenhouse, these correlations were extremely strong ($r > 0.8$).

The performance of populations from geographic regions peripheral to the region of study is presented in table 7, relative to that expected for populations from the upper Snake River drainage at similar elevations. Populations from the Wasatch Mountains are of slightly lesser growth potential and slightly higher hardiness than populations from the upper Snake. But, the populations tested from the lower Snake were of considerably lesser growth potential and higher hardiness than those from the upper Snake. However, disjunct populations from Deadline Ridge are of higher growth potential and lesser hardiness than populations from similar elevations in the upper Snake.

DISCUSSION

Genetic differentiation between populations from the upper Snake River Basin, like that for populations from northern Idaho (Rehfeldt 1983), Utah (Rehfeldt 1985a), and Oregon (Stoneman 1985), occurs along relatively steep clines. Differentiation was detected for a variety of traits, most of which were intercorrelated. Strong intercorrelation of adaptive traits results from either or both genetic linkage and parallel selection. Regardless, coherence (Clausen and Hiesey 1960) typifies the system of genetic variability for a species such as lodgepole pine that is physiologically specialized for specific environments. Populations from mild environments display a high growth potential and relatively low hardiness; populations from severe environments express high hardiness and low growth potential. Adaptation can be viewed as a balance between selection for high growth potential in mild environments and selection for high cold hardiness in severe environments.

Adaptive clines parallel environmental gradients. Temperatures and frost-free periods sharply decrease as elevation increases. Consequently, elevational clines are steep. On the average, populations separated by 3,000 feet elevation are expected to differ, for example, by 42 percent in 3-year height, by 20 percent in both spring and fall frost injury, and by 0.3 inch in leaf length.

A comparison of figures 4 and 5 shows that geographic patterns of genetic variation closely parallel environmental gradients in temperature but are poorly related to precipitation gradients. In fact, the geographic patterns presented in figure 4 nearly duplicate the environmental gradients represented by the length of the frost-free period (fig. 5). Patterns of genetic variation that arc to the east of the rugged Teton Range respond to the relatively mild climates that also extend east of this mountain range.

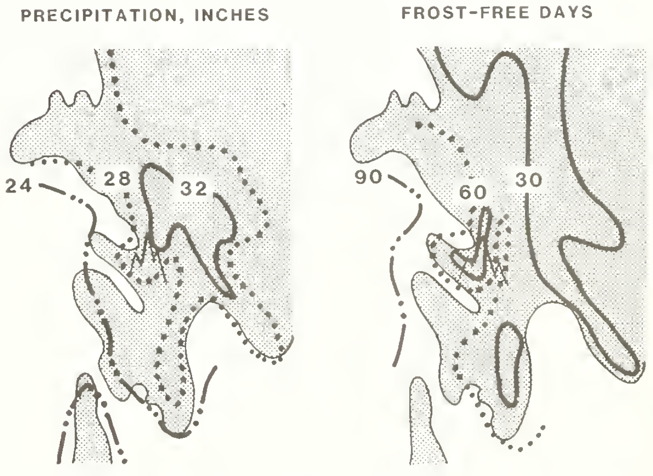


Figure 5.—Geographic patterns in precipitation and the frost-free period for the upper Snake River Basin (from U.S. Department of Commerce 1968).

Elevational clines are much steeper than the geographic. A comparison of these clines can be made by noting that in figure 4, each geographic band, situated between any two contours, is standardized for elevation. Each band is equivalent to the amount of genetic differentiation that occurs across 302 feet elevation for 3-year height, 315 feet for duration of elongation, 935 feet for leaf length, and 1,377 feet for fall freezing injury, respectively. Thus, in a region approximately 200 miles from north to south, the geographic clines (fig. 4) in those variables for which population differentiation was pronounced (table 5) are equivalent to the genetic differentiation that occurs within about 1,000 feet elevation at a single locality.

Patterns of adaptive variation between populations have direct implications in forest management. To limit maladaptation in planted trees, seed transfer guidelines must reflect adaptive variation. One estimate of an appropriate limit to seed transfer involves the smallest geographic or elevational interval across which differentiation can be detected (Rehfeldt 1979). This interval is estimated by the ratio *lsd*(0.2)/b, where b is the regression coefficient and *lsd*(0.2) is derived from the analysis of variance as the least significant difference between population means at the 80 percent level of probability. (A rather low level of probability is used to avoid accepting no differences when differences actually exist.)

Elevational intervals associated with *lsd*(0.2) include, for example, 604 feet for 3-year height, 738 feet for rate of elongation, 1,788 feet for late growth, and 2,752 feet for injury from fall freezing. These intervals suggest that the maximum elevational limits for biologically sound seed zones should not be much greater than 600 feet. This means that the transfer of seed from a single source should be limited to ±300 feet. Nevertheless, considerable genetic differentiation occurs across seed zones that occupy only 600 feet. These differences, for instance, amount to 9 percent in 3-year height and 5 percent in susceptibility to injury from the cold. Therefore, transfers of seeds beyond these limits can result in considerable productive losses in artificial reforestation.

Geographic patterns of variation (fig. 4) were scaled to a value of ½ *lsd*(0.2), and therefore lateral transfers of seed should be limited to about ±1 contour. This means that two geographic zones are sufficient for the upper Snake River Basin.

The appropriate size of seed zones should be practical operationally and economically. Thus, limits to seed transfer must accommodate biology, operational feasibility, and economics. When, however, administration demands an alteration in the guidelines proposed above, it should be remembered that each geographic band in figure 4 is equivalent genetically to a relatively small elevational interval within a band. Consequently, the geographic limits should be compromised. From the biological viewpoint, seed zones for the upper Snake River Basin should be considered as elevational zones with geographic stratification.

Regardless, populations of lodgepole pine from the drainages of the upper Snake River display patterns of genetic variation that typify the adaptation of the species to heterogeneous environments in other geographic localities. Populations appear to be physiologically attuned to specific environments, clines are steep, and genetic differences occur across relatively small environmental intervals. Differentiation between populations is easy to detect experimentally and is closely related to geography and elevation of the seed origin. Therefore, seed transfer in artificial reforestation should be greatly limited.

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U.S. GOVERNMENT PRINTING OFFICE: 1985-0-676-039/20030

Rehfeldt, G. E. Ecological genetics of *Pinus contorta* in the upper Snake River Basin of eastern Idaho and Wyoming. Research Paper INT-356. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 9 p.

Genetic differentiation of 60 populations of *Pinus contorta* primarily from eastern Idaho and western Wyoming was studied in field, greenhouse, and laboratory tests. Analyses of variables reflecting growth potential, morphology, cold hardiness, and periodicity of shoot elongation revealed population differentiation for a variety of traits. Regression models related as much as 83 percent of the variance of population means to the elevation and geographic location of the seed source. For genetic variation to be arranged along relatively steep environmental clines implies pronounced adaptive differentiation. As a result, seed transfer in reforestation should be restricted severely if maladaptation is to be controlled.

KEYWORDS: microevolution, adaptation, population differentiation, seed zones, seed transfer

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Research Station
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Research Paper
INT-357

January 1986

Visitor Attitudes Toward Wilderness Fire Management Policy—1971-84

CLEMSON UNIVERSITY
FEB 25 1986
PUBL

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RESEARCH SUMMARY

Fire suppression policies of the 20th century have significantly changed the evolution of many landscapes, compared to what would have occurred had natural fires been allowed to continue. Naturally occurring fires are now permitted in many wildernesses and National Parks under specified conditions. The public is often affected by this fire management policy, and needs to be informed about the role and effects of naturally occurring fire in wilderness settings.

Several studies suggest growing public acceptance of policies which manage fire rather than suppress it, particularly in wilderness settings. Trends in attitudes and knowledge levels have, however, not been investigated. Public attitude towards manager-ignited fires have not been investigated either. This study was designed to replicate an earlier study (1971) of visitors to the Selway-Bitterroot Wilderness to determine if attitudes and knowledge levels have changed.

Visitors using four trailheads on the eastern side of the wilderness were sampled. Each visitor completing a special registration card was sent a mail-return questionnaire. The final sample size totaled 274 people, reflecting an 83 percent response.

Compared to the earlier study, respondents were more knowledgeable about natural fire effects: the average correct score on the 11-item fire effects quiz was 64 percent; it was 53 percent in 1971. Most visitors preferred some type of fire management policy; the earlier study reported a majority of visitors preferring fire suppression.

About half the visitors felt that manager-ignited fires would be beneficial to the wilderness; about 16 percent thought that such fires would be detrimental; and about one-third were unsure of the effect. Individuals who felt that manager-ignited fires would be beneficial cited specific reasons for their feelings, such as benefits to wildlife, reduced fire hazard, and so on. Those unsure or feeling such fires would be detrimental did so because they thought fire in wilderness should be natural or were concerned about loss of animals.

The study also investigated factors associated with attitudes and knowledge levels. The relationship between fire management attitudes and fire effects knowledge was relatively strong (gamma = 0.51). Level of educational attainment and previous experience in the Selway-Bitterroot Wilderness were significantly associated with knowledge levels.

The data suggest that visitors to this wilderness are more supportive of managing naturally occurring fires than they were in 1971. Those with favorable attitudes toward manager-ignited fires tend to cite reasons not dependent on wilderness values. Those opposing these types of fires did so because they feel they interfere with natural processes. The study results suggest the need for more public discussion of the rationale and philosophy of manager-ignited fires.

The data also suggest that information given to the public may be helpful in increasing knowledge levels and changing attitudes. While no specific cause-effect relationships were studied, it appears that the more liberal attitude of visitors to this wilderness toward fire management may be partly due to the amount of information available in the local area.

Visitor Attitudes Toward Wilderness Fire Management Policy—1971-84

Stephen F. McCool
George H. Stankey

INTRODUCTION

The historical role of naturally occurring fire in shaping the character of many American landscapes has become an accepted ecological principle. Prior to the coming of the Europeans, natural fires had a major influence in producing a variety of vegetational mosaics. Fire suppression policies of the 20th century, however, significantly changed the evolution of many landscapes compared to what would have occurred had natural fires been allowed to continue. Although natural fires can no longer be allowed to burn in many places because of resource values or danger to the public, such fires may be permitted in many wildernesses and National Parks under specified conditions—if they achieve certain objectives.

Land managers and researchers acknowledge the validity of these prescribed fires, but what does the public think of the idea? Such a question is important because the public is affected by fire management policy—directly through closures of areas and trails, decreased visibility, and increased air pollution due to smoke during a fire, and indirectly through changes in the landscape and resulting effects on wildlife populations. In his discussion of the major philosophical aspects of this issue, Worf (1985) emphasizes that public awareness is important in gaining support for the use of fire in wilderness. The public is affected by fire management policies, and it should be informed and educated about the role and effects of naturally occurring fire in wilderness settings.

Disseminating information about fire's natural role and effects is an important step in establishing public support. In 1971, a study of visitors to the Selway-Bitterroot Wilderness showed that knowledge of fire effects was positively associated with attitudes toward fire management (Stankey 1976). Most respondents favored some type of fire suppression policy rather than a more liberal policy allowing fires to burn under certain conditions. Levels of knowledge were generally quite low. Stankey found that the average correct score on an 11-item fire effects test was only 53 percent. Since the time of the Stankey study, land-managing agencies have expended considerable effort in providing information to the public about the role of fire in shaping the landscape. One objective of this effort has been to increase the level of recognition and public acceptance of the natural role of fire. Have such efforts succeeded? Is the public more knowledgeable about the effects of fire? Are wilderness users more willing to accept fire management policies that permit lightning fires to burn as prescribed fires rather than suppressing them all as wildfires?

A review of the literature suggests that public acceptance of fire as a management tool is growing. Whereas the literature review conducted by Stankey in 1976 revealed virtually no studies that examined public attitudes toward fire management, the topic has been the focus of several recent investigations. For example, Taylor and Daniel (1984) reported that respondents considered burned forests visually acceptable under certain conditions, particularly when lightly burned. Cortner and others (1984) found considerable support for policies favoring prescribed fire rather than complete suppression in the Tucson, AZ, area. These cross-sectional studies suggest significant changes in visitor knowledge and attitudes toward fire suppression policies during the last decade.

Specific trend information about changes in attitudes or knowledge about natural fire is less readily available. Lucas (1985) indicates that visitors to the Bob Marshall Wilderness in 1982 were more supportive of allowing natural fires to burn than those he studied in 1970. But his study did not investigate knowledge levels. Because an understanding of public knowledge levels about the role of fire and the trend in this understanding is important for developing public information programs and evaluating their effectiveness, we initiated a study designed specifically to examine these issues.

METHODS

The research reported here replicates in content and method the Stankey study of Selway-Bitterroot Wilderness users in order to determine trends. In the current study, summer visitors were selected from those registering at four trailheads on the eastern side of the Wilderness. The trailheads ranged in use levels from very heavy to very light. A total of 330 visitors were sent a mail-return questionnaire, followed by a postcard reminder 1 week later, and a second questionnaire 2 weeks after the postcard. A total of 275, or 83 percent of those sampled, responded to the study. In 1971, Stankey sampled visitors to the same wilderness but included some fall visitors as well as summer visitors. His initial sample was 217. The mail-return questionnaire yielded an 84 percent return rate, for a net sample size of 183. Despite some sampling differences, the two studies are similar in terms of the population studied.

To test knowledge, a series of 11 statements were developed about the role and effects of naturally occurring fire in the Northern Rocky Mountains. Respondents were asked to check each statement as "basically true," "basically false, or, if uncertain, "not sure." The 11 statements are shown with the correct answer underlined in figure 1. Correct answers were based on consultation with scientists at the Intermountain Fire Sciences Laboratory, Missoula, MT.

Respondents were presented with a list of nine different policy statements about wildfire in wilderness (fig. 2). These statements ranged from advocating suppression of all fires to advocating no suppression whatever. The statements were based on the Sherif and others' (1965) social judgment approach to measuring attitudes.

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1. Forest fires usually result in the death of the majority of the animals in the area.

   Basically True **Basically False** Not Sure

2. Most forest fires in the Northern Rocky Mountains are started by lightning.

   Basically True Basically False Not Sure

3. Past forest fires have not changed the way in which the Northern Rocky Mountain forests developed.

   Basically True **Basically False** Not Sure

4. The elimination of forest fire in the Northern Rockies would result in a change in the kinds of plants and animals found in the area.

   Basically True Basically False Not Sure

5. Complete control of all forest fires would reduce the habitat of animals such as elk.

   Basically True Basically False Not Sure

6. The majority of forest fires that occurred in the Rocky Mountains before the pioneers covered hundreds of thousands of acres.

   Basically True **Basically False** Not Sure

7. Fire often proves useful in making minerals and nutrients available to plants and trees.

   Basically True Basically False Not Sure

8. Some kinds of trees found in Northern Rocky Mountain forests would gradually disappear over time if all fires were eliminated.

   Basically True Basically False Not Sure

9. Forest fire can be an important force in controlling outbreaks of disease and insects in forests.

   Basically True Basically False Not Sure

10. Intensive fire control has actually increased rather than reduced the chances of a very large fire occurring.

    Basically True Basically False Not Sure

11. Forest fires are partly responsible for some of the open meadows and grassy fields one finds in the Northern Rocky Mountains.

    Basically True Basically False Not Sure

Figure 1.—True-false test to determine level of knowledge about the role of fire in the Northern Rocky Mountains used in 1971 and 1984 (correct answer underlined).

A. It is absolutely necessary that all forest fires be put out as soon as possible in our wilderness areas.
B. It would probably be best if all forest fires were put out as soon as possible in our wilderness areas.
C. Generally, it would be preferable if all forest fires in wilderness were put out as soon as possible.
D. It is hard to decide what the policy toward forest fires in wilderness should be, but probably they should be put out as soon as possible.
E. It is hard to decide whether we should allow forest fires to burn in our wilderness areas or not.
F. It is hard to decide what the policy toward forest fires in wilderness should be, but probably we should allow small, "safe" ones to burn.
G. Generally, it would be preferable if small, "safe" forest fires were allowed to burn in our wilderness areas.
H. It would probably be best if most forest fires were allowed to burn in our wilderness areas.
I. It is absolutely necessary that we allow all forest fires to burn in our wilderness areas.

Figure 2.—Alternative wilderness fire suppression statements included in both 1971 and 1984 studies.

Respondents were asked to indicate which statement most nearly matched their own personal opinion, other statements which they found acceptable, and the one statement that they considered most objectionable.

RESULTS AND DISCUSSION

Have knowledge levels shifted in the 13 years between studies? Table 1 shows the results of the fire effects quiz for both years. As mentioned, the average correct score was 53 percent in the first study. In 1984 the average correct score was 64 percent, an 11 percent increase and an indication that current wilderness users are more knowledgeable about fire effects. Nevertheless, as table 1 shows, the changes in knowledge levels were not consistent on all questions. For some questions there was little increase in reported knowledge levels, while the changes were dramatic for others. For example, most visitors in both years were unable to correctly answer the question (6) about the size of natural fires. Yet there was a major increase in the percentage of correct answers dealing with the influence of fire on nutrient cycling. Table 2 shows the distribution of test scores among the categories used by Stankey. Note there has been nearly a 50 percent decline in the percentage of individuals scoring in the very lowest category and a major increase in the percentage of people scoring in the highest two categories.

Table 1.—Percentage responding correctly to fire knowledge test items for 1971 and 1984[1]

Question (answer)	Percentage responding correctly	
	1971	1984
1. Forest fires usually result in the death of the majority of the animals in the area. (F)	52	51
2. Most forest fires in the Northern Rocky Mountains are started by lightning. (T)	63	63
3. Past forest fires have not changed the way in which the Northern Rocky Mountain forests developed. (F)	66	62
4. The elimination of forest fire in the Northern Rockies would result in a change in the kinds of plants and animals found in the area. (T)	55	71**
5. Complete control of all forest fire would reduce the habitat of animals such as elk. (T)	50	59*
6. The majority of forest fires that occurred in the Rocky Mountains before the pioneers covered hundreds of thousands of acres. (F)	23	26
7. Fire often proves useful in making minerals and nutrients available to plants and trees. (T)	55	79**
8. Some kinds of trees found in Northern Rocky Mountain forests would gradually disappear over time if all fires were eliminated. (T)	53	67**
9. Forest fire can be an important force in controlling outbreaks of disease and insects in forests. (T)	67	84**
10. Intensive fire control has actually increased rather than reduced the chances of a very large fire occurring. (T)	40	58**
11. Forest fires are partly responsible for some of the open meadows and grassy fields one finds in the Northern Rocky Mountains. (T)	54	63*

[1] *Difference in percentage answering question correctly statistically significant at $\alpha = 0.10$.
**Difference in percentage answering question correctly statistically significant at $\alpha = 0.05$.

Table 2.—Test score distribution by year, in percentage ($\chi^2 = 23.25$, $\alpha = 0.001$)

Score	1971	1984
	---- Percent ----	
0 – 35	22.1	12.2
36 – 44	9.9	9.9
45 – 54	9.9	7.6
55 – 64	16.6	12.9
65 – 72	15.5	11.8
73 – 81	11.0	14.4
82 – 91	13.3	24.0
92 +	1.7	7.2

Table 3 shows a corresponding shift in attitudes toward fire management. This table indicates which of nine fire management policies respondents found most acceptable. In 1971 the majority (56 percent) of the users questioned favored a fire suppression approach (statements A through D). The 1984 study indicates only about 17 percent supported these policies, and only 5 percent supported complete suppression. Interestingly, only a small percentage in either year supported a policy of completely letting all fires burn, suggesting that visitors remain unwilling to support extreme positions. Over 70 percent of the 1984 sample, however, supported a policy of allowing fires to burn in wilderness (statements F through I).

Table 3.—Most acceptable fire management policy by year in percentage, rounded to nearest whole number ($\chi^2 = 75.00$, $\alpha = 0.001$)

Attitude	1971	1984
	Percent	*Percent*
A (most restrictive)	31	5
B	8	4
C	8	4
D	9	4
E	4	8
F	13	23
G	18	23
H	7	26
I (most permissive)	2	1
	100	98

Respondents were also asked to indicate the one statement they found most objectionable. In 1984, the only two statements found objectionable by more than 2 or 3 percent of the sample were the two extreme positions. In 1971, many respondents found other intermediate fire management policies objectionable.

An issue of growing concern is the deliberate use of prescribed fire to achieve wilderness objectives: should wilderness managers deliberately ignite some fires in the wilderness? A prescribed fire ignited by the manager is set at a predetermined time to achieve a predetermined objective. How do wilderness users feel about this type of fire management policy?

The 1984 study asked two questions about the use of prescribed fire. Because Cortner and others (1984) had demonstrated that awareness of prescribed fire was associated with approval of its use, we first asked respondents if they were aware of the use of prescribed fire in areas outside wilderness. About two-thirds of our respondents had heard of the practice, in distinct contrast to the Cortner and others study where the figure was 84 percent. Our 1984 study also asked respondents if they believed "using prescribed fire (igniting the forest under strict supervision of management) in some wilderness areas" would be detrimental or beneficial. Nearly 50 percent felt that such human-ignited prescribed fires would be beneficial; slightly more than one-third indicated they were "unsure"; only 16 percent felt that such fires would be detrimental. Of those aware of the practice of prescribed fire outside wilderness, 27 percent were unsure of the effects of human-ignited prescribed fires in wilderness. This is in contrast to those who were unaware of prescribed burning: 51 percent were unsure of the effects of human-ignited prescribed fires in wilderness. Interestingly, less than 4 percent of the respondents unaware of prescribed burning practices outside wilderness believed that such fires would be detrimental, while more than 22 percent of those aware of this practice in areas outside wilderness thought prescribed fires in wilderness detrimental.

Respondents were asked to explain their beliefs about human-ignited prescribed fires in wilderness. Table 4 shows the major responses. For those who believed that results would be beneficial, the most frequently cited reasons included reduced fire hazard, improved wildlife habitat, the creation of openings in the forest, better pest control, and restoring fire to its natural ecological role. Those who felt that such a fire policy would be detrimental indicated that the importance of maintaining natural processes through a natural fire policy was a concern. Individuals who were unsure of their feelings stated that they needed more information about the conditions that would guide human-ignited prescribed fires

Table 4.—Study (1984) respondents' reasons for believing that planned ignition may be beneficial, detrimental, or "unsure," in percentage

Reason	Beneficial	Detrimental	Unsure
	Percent	*Percent*	*Percent*
Reduced fire hazard	27.4		1.6
Improved wildlife habitat	37.6		1.6
Creates openings	20.5		
Restore fire to natural role	12.8		3.1
Pest control	8.5		
Stimulates growth	7.7		
Nutrient release	8.5		
Wilderness should be natural	.9	40.0	12.5
Loss of animals		10.0	4.7
Possible mismanagement		10.0	1.6
Natural fire best	1.7	27.5	6.3

and that wilderness areas should be places for natural processes. In general, it seems that those who oppose or are unsure about prescribed fires ignited by managers are concerned about the intrusion of such a policy into the operation of natural processes. Those who favor prescribed fires from human ignition do so less on philosophical grounds than on the specific benefits to the resource they see. This pattern of reasoning has important ramifications that we will elaborate on later.

Factors Associated with Attitudes

In the 1971 study, the only significant variable found to be related to attitudes toward fire policy was the level of knowledge about fire effects. Stankey found a gamma of 0.57 between fire effects knowledge and selection of a policy as most acceptable. In the current study, we also found a high level of association, a gamma of 0.51. Both results suggest the critical role information can play in influencing how people feel about fire management.

How do other factors influence attitudes? We examined how age, educational attainment, and previous experience in the Selway-Bitterroot were associated with attitudes and knowledge levels. In addition, we were interested in how particular expectations about the wilderness recreation experience were associated with attitudes and knowledge. Specifically, we wanted to know whether individuals who thought that learning about nature (Driver 1977) was important scored high on the fire effects test. Likewise, the association between attitudes and the importance of learning about nature was of interest.

Spearman's rank order correlation coefficient was used to identify associations among age, education, and knowledge. Although the correlation between age and knowledge was significant at $\alpha = 0.05$, it was so low (0.09) as to have little practical utility. The correlation between educational attainment and fire effects knowledge, however, was considerably higher (0.31). Respondent's previous experience in the Selway-Bitterroot was also associated with knowledge levels, as follows:

Previous visits	Mean score
	Percent
Yes	64
No	54
Total visits	
1 – 3	53
4 – 7	64
8 – 12	69
> 12	69

Differences among experience levels are statistically significant at $\alpha = 0.05$.

Individuals were asked to indicate how important learning about nature was to their wilderness experience. Two items were used to measure this:

1. To learn more about nature.
2. To understand the natural world better.

Respondents were asked to indicate how important each was, on a scale of (1)—not at all important to (6)—extremely important, when they were planning their wilderness trip. The scale had a Cronback's alpha reliability coefficient of 0.85. The average score on this scale for the whole sample was 4.2, indicating that this was a moderately important motivation. When correlated with knowledge level, however, the Spearman's rank order correlation coefficient was only 0.11. Although statistically significant, the coefficient has little practical usefulness. When correlated with attitudes toward fire management, the coefficient was lower (0.05), and not significant. As shown in table 5, attitudes toward human-ignited prescribed fires in wilderness are also related to knowledge of fire effects. Nevertheless, those with the highest scores on the fire effects test exhibited a considerable uncertainty about the consequences of human-ignited prescribed fires in wilderness settings. These individuals might be responding to this question in terms of the philosophical values of fire in wilderness more than the direct effects of such prescribed fires.

In summary, previous experience in the Selway-Bitterroot Wilderness, age, and educational attainment were associated with level of knowledge about fire effects. Knowledge about fire effects and awareness of the use of prescribed fire, however, were strongly associated with attitudes toward wilderness prescribed fire policies. The motivation of learning about nature was not meaningfully associated with either knowledge levels or attitudes toward fire management. This might have been because the average score on this scale was relatively high, thereby eliminating the variance needed for a high correlation, or it might have been because the items were not good measures.

Table 5.—Association between knowledge of fire effects and attitude toward planned ignition in wilderness, in percentage, 1984 study ($\chi^2 = 27.87$, $\alpha = 0.015$)

Fire test score	Beneficial	Detrimental	Unsure
	Percent		
0 — 35	27.6	10.3	62.1
36 — 43	28.6	23.8	47.6
44 — 54	47.4	15.8	36.8
55 — 63	46.9	9.4	43.8
64 — 72	51.6	9.7	38.7
73 — 81	57.9	15.8	26.3
82 — 91	61.7	23.3	15.0
92 — 100	44.4	16.7	38.9

CONCLUSIONS

The data indicate that Selway-Bitterroot Wilderness users are more knowledgeable about fire effects than they were 13 years ago. Their attitudes toward fire management also exhibit significantly more acceptance of allowing some fires to burn in wilderness. This study did not attempt to link such changes to specific information sources or campaigns. Wilderness managers for the Selway-Bitterroot, however, have attempted to provide considerable information to residents in the local area and to wilderness users. One of the first fires allowed to burn in a Forest Service wilderness occurred in the Selway-Bitterroot. This fire, and later fires and their effects, received considerable publicity. Although we cannot establish a cause-effect relationship, the results indicate that knowledge levels have increased and attitudes have become more supportive with regard to the role of fire in wilderness, changes possibly linked to the increased amount of information made available over the past decade.

The findings with respect to experience are noteworthy and do have management implications. Experience levels in wilderness in general seem to be increasing, suggesting that visitors will become more knowledgeable about the resource, including various aspects of natural fire occurrence and effects. It is not clear whether this is because increased experience in wilderness promotes a greater awareness of, and sensitivity to, the influence of fire in natural systems or because increased experience leads people to seek out more information to promote their understanding of the area. Both explanations probably play a role. Whatever the reason, increased experience levels imply that visitors will be more supportive of allowing some natural fires to burn under prescription.

Our data indicate that those favoring a more liberal fire policy (management-ignited prescribed fires) expect specific benefits. But many of the benefits cited are incidental to the area's management as wilderness. For example, such fires in wilderness will probably improve wildlife habitat or reduce the potential for damage to outside property and resources; however, the main goal is restoration of natural processes. The fact that fire might result in these outcomes could build pressures to burn it to achieve nonwilderness-dependent objectives, a concern that led Worf (1985) to seriously question manager-ignited fires. Our data suggest that many users might expect fire to be used to achieve nonwilderness goals. Managers will need to carefully scrutinize any proposed human-ignited prescribed fires to make sure they satisfy wilderness-dependent purposes. Whether the support for human-ignited prescribed fires will be translated into political support is another issue. In our study, those who were unsure of the effects of prescribed burning or who thought it would be "detrimental," appeared to do so on philosophical grounds rather than because of possible negative effects to the resource itself. Again, Worf (1985) argued that such issues need to be resolved before implementing prescribed fires.

The data also indicate where information campaigns can be more specifically focused. There is a need for more information about the size of natural fires, wildlife mortality, ecological effects of fire suppression, and the capability of natural fire to create forest openings.

This study does not allow direct measurement of the effects of information on knowledge and attitudes. We can only infer that more information and more detailed information lead to greater public understanding about the role of fire. Useful research projects would be to compare the effects of different information treatments on knowledge and attitudes of wilderness visitors and also the general public. The results of such studies would be helpful in designing future information programs, particularly with regard to the type, detail, and timing of information presented to different target audiences.

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Visitors to the Selway-Bitterroot Wilderness, MT, were asked about their knowledge of fire effects and attitudes toward fire management in wilderness settings. In comparison to a similar 1971 study, visitors were more knowledgeable about fire effects and more supportive of fire management rather than fire suppression. About half the visitors felt that manager-ignited fires would be beneficial to wilderness, about 16 percent felt these fires would be detrimental, and about one-third were unsure.

KEYWORDS: wilderness fire management, wilderness policy, visitor attitudes

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Research Paper
INT-358

July 1985

Measurement of Field Resistance, Rust Hazard, and Deployment of Blister Rust-Resistant Western White Pine

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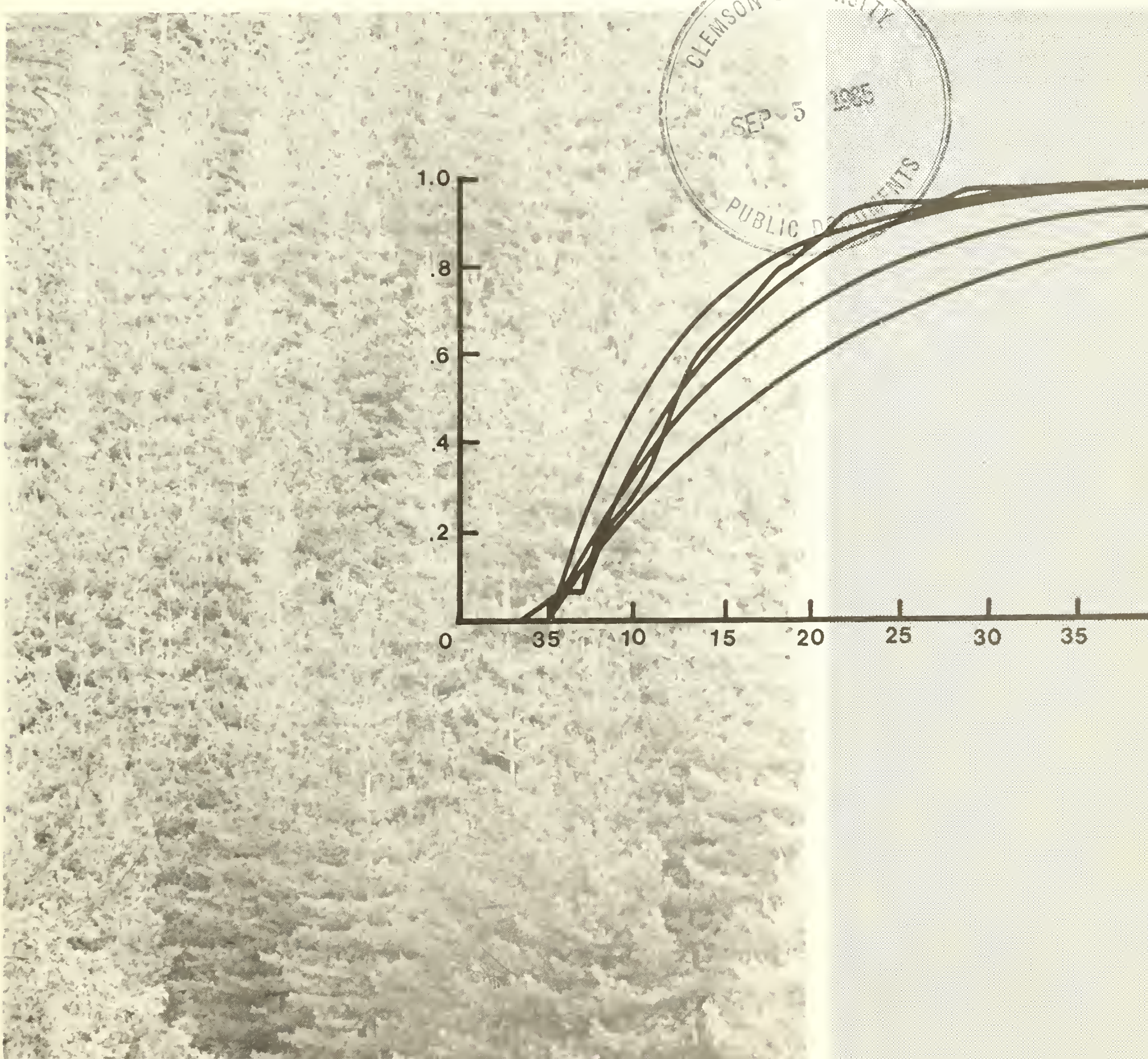
CLEMSON UNIVERSITY
SEP 5 1985
PUBLIC DOCUMENTS



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RESEARCH SUMMARY

Three white pine plantations, composed of materials of several levels of resistance from early generations of the blister rust resistance breeding program, were compared on the basis of annual infection and mortality rates. The sites varied in blister rust hazard; resistant materials were consistent in their performance, and the infection data behaved as one would expect if the genetic and environmental assumptions of the simple interest disease progress model were violated.

Presumably, the resistant populations violate the genetic assumptions to the extent of their resistance, and any assessment of resistance performance must take into account both environmental as well as genetic violation. Field performance is discussed in relation to measuring hazard on wild seedlings.

Measurement of Field Resistance, Rust Hazard, and Deployment of Blister Rust-Resistant Western White Pine

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INTRODUCTION

Soon after the white pine blister rust fungus (*Cronartium ribicola* J.C. Fisch. ex Rabenh.) was discovered on western white pine (*Pinus monticola* Dougl.) in the Inland Empire, plant quarantines were established in an attempt to prevent further introductions. In spite of efforts to control the intensification and spread of the disease by eliminating the obligate alternate host, *Ribes* species, the epidemic continued until virtually all the area had been exposed. The *Ribes* eradication programs were continued in the hope that losses to the disease could be held to an acceptable level. At the same time, hopes were that numerous studies on various aspects of the ecology, physiology, and pathology of the disease would lead to new control measures. Attempts at direct chemical control of the disease in infected trees were one result of that research. However, in 1967, after nearly four decades of control efforts, researchers concluded that none of the control measures were sufficiently effective to warrant their continuation (Ketcham and others 1968).

Although efforts to control the rust fungus were not successful, efforts to produce trees resistant to the rust are showing considerable promise (Bingham and others 1960). Since 1970, approximately 1,300 lb of seed containing low to moderate levels of rust resistance have been produced in a research breeding arboretum and a grafted seed orchard. Additional orchards designed to produce seeds containing higher levels of resistance are beginning to produce (Hoff and McDonald 1980), but the demand still exceeds the supply. Even if there were enough high-quality seed, it might not be good policy to challenge the rust with only highly resistant trees because this could result in widespread selection for more virulent fungal races. Indeed, at least one new race has already made an appearance (McDonald and others 1984).

A single response that would address both shortage of resistant seed and maintenance of genetic breadth is alignment of resistance to hazard (McDonald and Hoff 1982). This response, of course, presumes that hazard does indeed vary. A tour through northern Idaho western white pine stands readily demonstrates that 60 years after introduction of *C. ribicola*, the epidemic is not of equal intensity and impact. Of the many elements of the disease complex, the most important seems to be the number, distribution, and species of *Ribes* (McDonald and others 1981). We know ribes populations vary greatly from thousands of bushes per acre to total absence. Records from the early ribes eradication program (USDA 1950) indicated more ribes-free stands of white pine as well as lower densities (table 1) in the Kaniksu National Forest where 46 percent of the white pine stands were ribes free, in contrast to the more southerly St. Joe National Forest with only 15 percent ribes-free stands. (The two forests today are part of the Idaho Panhandle National Forests.)

There is also evidence of variation in hazard within a given drainage. For example, on the Priest River Experimental Forest replicate plantings on three sites were established in 1971 to investigate genetic variation within and among stands of white pine (Steinhoff 1979). Blister rust infection (percentage of stems infected),

Table 1.—Ribes eradicated per acre with the first working, 1923 to 1950

		Mean number of ribes plants per acre					
Operation	Gross acres	*R. lacustre*	*R. viscosissimum*	*R. petiolare*	*R. inermi*	Others	Total
Clearwater	423,980	95	123	8	2	*	228
St. Joe	542,520	86	152	6	6	*	244
Coeur d'Alene	347,030	111	46	*	14	1	172
Kaniksu	492,600	47	65		9	*	121

*Less than 1 per acre.

mortality, and ribes abundance on these sites indicate (McDonald and Hoff 1982) that hazard varies a great deal over distances of less than 1 mile, and that relative abundance and species of local ribes plants is closely associated with degree of damage.

This paper reports on field performance of western white pine trees with various levels of heritable resistance to blister rust in plantations where the rust hazard ranged from moderate to high. Field resistance was estimated two ways: reduced infection rate (percentage infected per year) and lower proportion dead.

MATERIALS

The blister rust resistance breeding program was started about 1950. Western white pine trees selected for phenotypic resistance were mated, and the resulting progenies were inoculated in nursery beds to determine genotypic resistance (Bingham and others 1969). Open-pollinated cones were also collected from the selected trees and the resulting seedlings used in the resistance testing program.

Excess seedlings from controlled and open pollinations were used to establish field plantings at Priest River Experimental Forest, Deception Creek Experimental Forest, and at Emerald Creek near Clarkia, ID. Planting was done in 1955, 1956, 1957, and 1959 with 22 to 45 lots established per year in three blocks at each location. The number of seedlings available varied greatly from two to 24 per lot per location. Open-pollinated control lots from cankered and presumably nonresistant trees growing with the phenotypically resistant selections were included in each planting.

Because of the unbalanced design, critical analysis of individual lots is of doubtful value. However, the individual parents were classified on the basis of nursery inoculations (Bingham and others 1969), and their progenies were grouped into five resistance classes as follows:

1. Crosses between good general combiners (GCA × GCA).
2. Crosses involving at least one parent not classed as a good combiner (Other Crosses). Most of these involved one GCA parent.
3. Open-pollinated progeny of GCA's (GCA OP).
4. Open-pollinated progeny of parents not classed as good combiners (Other OP).
5. Susceptible controls (Controls).

Records from previous examinations were surveyed, and any trees recorded as severely infected or rust-killed at an earlier date but not present in 1980 were added to the rust mortality count. Trees killed directly or indirectly by blister rust were included in counts of infected trees.

Naturally regenerated white pines were found in fair abundance within the plantings at each location. These volunteers ranged in age from less than 10 years to about 23 years. The rust condition (including rust-killed trees) of a sample of volunteer white pines was recorded at each location. For each wild tree sampled, the age was estimated by count of annual whorls.

Field performance was assessed as proportion infected and proportion dead in 1980. Plant disease epidemics usually develop (see Pfender 1982) according to either a simple or compound interest model (Van der Plank 1975; Zadoks and Schein 1979). Knowledge about the biology of western white pine blister rust leads to the conclusion that this system fits the simple interest model. This model yields disease progress curves that eventually reach 100 percent infection if the following assumptions are met (Baker and Drury 1981): (1) a random distribution of inoculum, (2) a random occurrence of infection conditions, and (3) all members of the host population are susceptible to the pathogens. Many times epidemics do not meet these assumptions (Grogan and others 1980).

Using McDonald and Hoff's simple interest formula for eventual 100 percent infection:

$$r = \frac{1}{t_2} \log e \frac{1}{1 - X_2} \qquad (1)$$

where

t_2 = time of measurement

X_2 = proportion infected,

the infection rates through 1970 for each resistance class in the Priest River and Deception Creek plantings were calculated from data reported by Steinhoff (1971). These rates were used to project expected proportion of trees infected in 1980:

$$X = 1 - e^{-rt_3} \qquad (2)$$

where

X = expected proportion infected at time t_3 = (1980)

r = infection rate calculated from equation 1.

The calculated expected infections and observed 1980 infections were used in chi-square analysis to assess the fit of the simple interest model.

Detection of incipient white pine blister rust cankers during the first year after infection is impossible because many cankers require more than 1 year to appear. Because older cankers are easily seen, 2 years were arbitrarily deducted from the time since planting to estimate "years of exposure" for calculation of annual infection rates. Infection rates calculated on the basis of 1980 data for all resistance classes, establishment years, and locations were subjected to analysis of variance.

Mortality percentages for the various classes, years, and locations, transformed to arcsin of the square root, were similarly analyzed.

RESULTS

This study yielded three principal results: (1) expectations relative to the simple interest model of disease progress, (2) temporal and spatial variation of infection rates, and (3) spatial and temporal variation of mortality levels.

The Simple Interest Model for Disease Progress

Chi-squares from the observed and expected infections based on the simple interest formula are listed in table 2. Considering all progeny categories, establishment years, and locations, the total and pooled chi-squares are high and indicate highly significant departure of the observed

Table 2.—Chi-square analysis of total observed blister rust infection in white pine resistance classes at two locations and infection expected on the basis of 1970 infection rates projected by the simple interest model

Location and infection year	Resistance class	Number of trees	1970 infection rate	1980 infection Expected No.	1980 infection Observed No.	Chi-square
PR-1955	GCA × GCA	137	0.0169	44.1	39	0.59
	Other Crosses	111	.0185	38.5	31	1.46
	GCA OP	96	.0277	45.2	39	.85
	Other OP	48	.0443	30.7	34	.35
	Controls	23	.0640	17.7	17	.03
PR-1957	GCA × GCA	63	.0281	28.1	19	2.95
	Other Crosses	108	.0339	67.2	52	3.44
	GCA OP	126	.0436	75.6	70	.41
	Other OP	39	.0868	32.7	28	.68
	Controls	60	.0761	47.9	41	.99
PR-1959	GCA × GCA	91	.0288	38.3	31	1.39
	Other Crosses	122	.0365	61.0	60	.02
	GCA OP	39	.0522	30.6	19	4.40
	Other OP	70	.0837	55.7	51	.40
	Controls	31	.0603	21.1	20	.06
DC-1955	GCA × GCA	154	.0192	55.0	48	.89
	Other Crosses	138	.0346	75.8	62	2.51
	GCA OP	95	.0591	70.6	64	.62
	Other OP	43	.0761	35.5	34	.06
	Controls	34	.1336	32.4	32	.01
DC-1957	GCA × GCA	86	.0385	47.6	34	3.89
	Other Crosses	159	.0394	89.5	61	9.08
	GCA OP	174	.0477	110.0	88	4.40
	Other OP	38	.0909	32.4	29	.36
	Controls	88	.1074	78.7	75	.17
DC-1959	GCA × GCA	86	.0363	42.9	28	5.18
	Other Crosses	111	.0320	50.5	38	3.09
	GCA OP	37	.0480	22.2	16	1.73
	Other OP	70	.1018	59.5	47	2.78
	Controls	27	.0813	21.2	17	.83

	All classes df		Prob.		Susceptible classes only (Other OP and Controls) df		Prob.
$\Sigma\chi^2$	30	53.60	0.005	$\Sigma\chi^2$	12	6.72	0.85
Pooled χ^2	1	37.73	.001	Pooled χ^2	1	3.59	.05
Heterogeneity χ^2	29	15.87	.98	Heterogeneity χ^2	11	3.13	.98

from the expected infection frequencies (table 2). Almost all of the observed frequencies are lower than the expected. Because the heterogeneity chi-square has a high probability of being larger, the consistency of overestimation is confirmed.

Note, however, that the two most susceptible classes, Other OP and Controls, generally contribute relatively little to the total chi-square. Considering these two classes alone, the chi-square of 6.72 is a value that could be obtained by chance over 85 percent of the time, meaning that estimate and actual are not significantly different. The heterogeneity chi-square value for this subgroup (probability of a larger χ^2 by chance is 0.98) still indicates consistent overestimation.

Variation of Infection Rates

Although average annual infection rates as calculated did not provide highly reliable predictions of future infections, except for nonresistant trees, they did standardize infection data by removing effects of varying periods of exposure to the disease and provided a more stable measure of disease intensity up to the time of assessment. Infection rates based on data through 1980 (table 3) varied significantly among resistance classes and locations (table 4). The effect of planting year was not significant. Mean infection rates at Emerald Creek were significantly higher than those at Priest River at the 5 percent level (Duncan's multiple range test), and rates at Deception Creek were intermediate (table 3).

Table 3.—Total infection and infection rate by resistance class and planting location

Resistance classes	Priest River		Deception Creek		Emerald Creek		Mean[1]	
	Total infection	Infection rate	Total infection	Infection rate	Total infection	Infection rate	Total infection	Infection rate
	Percent		*Percent*		*Percent*		*Percent*	
GCA × GCA	30.9	0.018	34.4	0.019	46.7	0.031	37.3	0.026ab
Other Crosses	38.5	.024	39.2	.024	46.8	.030	41.2	.026ab
GCA OP	48.3	.032	53.7	.037	61.7	.049	54.6	.040b
Other OP	71.8	.061	74.2	.065	73.4	.071	73.1	.066c
Controls	68.9	.056	80.8	.089	86.0	.095	78.6	.080c
Mean[1]	51.7	.038a	56.5	.047ab	62.9	.055b		

[1] Column and row means of infection rates with different letter superscripts are significantly different at the 5 percent level of probability.

Table 4.—Analysis of variance of mean annual rate of blister rust infection through 1980 in progenies established at three locations in three planting years

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value
Total	44	0.0337		
Years (Y)	2	.0001	0.00007	NS
Locations (L)	2	.0021	.00107	3.82*[1]
Resistance classes (RC)	4	.0226	.00565	20.2**
Residual	36	.0099	.00028	

[1] * and ** indicate significance at the 5 and 1 percent levels, respectively.

Differences among resistance classes were consistent with expectation: over two-thirds of the total sum of squares in infection rates was due to resistance classes with the following contrasts (Duncan's multiple range test), significantly contributing to variation (table 3):

1. Infection rate of all select progenies combined was lower than that of the controls.
2. Progeny of controlled crosses had lower rates than open-pollinated progenies.

Note that the mean rate for open-pollinated progenies of trees other than the GCA's was not significantly lower (Duncan's multiple range test) than the controls and far higher than the rate for controlled crosses among these trees.

Rust data from white pine natural regeneration within the plantings were not included in the analysis of variance and, therefore, cannot be statistically compared with the planted trees. In most instances, however, the infection rate for volunteers was higher than that of planted trees, including the nonresistant control lots (table 5). At Deception Creek, the infection rate of young volunteer age classes was relatively low in contrast to other nonresistant classes.

Table 5.—Infection rate and mortality of naturally seeded volunteer white pines at three locations in contrast to planted susceptible controls

	Planted controls	Volunteers 11-20 yr exposure
Priest River		
Annual infection rate	0.056	0.089
Mortality (percent)	20.1	14.9
Number of trees	114	76
Deception Creek		
Annual infection rate	0.089	0.062
Mortality (percent)	27.1	16.7
Number of trees	149	1,221
Emerald Creek		
Annual infection rate	0.095	0.353
Mortality (percent)	27.9	11.1
Number of trees	43	48

Deception Creek - volunteers by age class

Number of trees	Years exposure	Infection rate	Mortality (percent)
121	6-10	0.042	8.3
630	11-15	.047	11.2
591	16-20	.078	22.2
14	21-25	.089	35.2

Table 6.—Percentage rust-related mortality by resistance class, location, and planting year

Resistance class	Planting location	Planting year 1955	1957	1959	Mean[1]
GCA × GCA	Priest	3.6	12.7	13.2	9.8
Other Crosses	River	4.5	6.5	10.7	7.2
GCA OP		4.2	11.1	17.9	11.1
Other OP		10.4	10.3	22.9	14.5
Controls		26.1	8.3	25.8	20.1
Mean		9.8	9.8	18.1	12.5^{x}
GCA × GCA	Deception	11.7	9.3	14.0	11.7
Other Crosses	Creek	15.9	16.4	13.5	15.3
GCA OP		20.0	17.8	21.6	19.8
Other OP		20.9	34.2	35.7	30.3
Controls		17.6	34.1	39.6	27.1
Mean		17.2	22.4	22.9	20.8^{y}
GCA × GCA	Emerald	4.5	20.0	27.1	17.2
Other Crosses	Creek	10.2	7.1	22.9	13.4
GCA OP		0	17.9	41.2	19.7
Other OP		7.7	10.0	25.7	14.5
Controls		14.3	10.5	58.8	27.9
Mean		7.4	13.1	35.1	18.5^{y}
GCA × GCA	All	6.6	14.0	18.1	12.9^{a}
Other Crosses		10.2	10.0	15.7	12.0^{a}
GCA OP		8.1	15.6	26.9	16.9^{a}
Other OP		13.0	18.2	28.1	19.8^{ab}
Controls		19.3	17.6	38.1	25.0^{b}
Mean[1]		11.4^{a}	15.1^{a}	25.4^{b}	

[1]Resistance class, location, and year means with different letter superscripts are significantly different at the 5 percent level of probability.

Table 7.—Analysis of variance of rust-caused mortality through 1980

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	44	3,419		
Locations (L)	2	344	172	3.25**[1]
Years (Y)	2	966	498	9.40*
Resistance classes (RC)	4	563	141	2.66**
Residual	36	1,915	53	

[1]* and ** indicate significance at the 5 and l percent levels, respectively.

Variation of Mortality Percentage

The percentage of trees killed by *C. ribicola* since establishment of the plantings was recorded by resistance class, location, and year (table 6). As was the case for infection rate, clear, consistent differences between resistance classes are evident. Analysis of variance (table 7) indicated that all major effects (resistance class, location, and establishment year) were significant. As was the case in infection rates, rust mortality was much lower at Priest River than at the other two locations (table 6).

In contrast to infection rates, the strongest single cause of variation in mortality was planting year. Rust mortality of trees planted in 1959 was approximately double that of trees planted in 1955 and 1957. Mortality was also unexpectedly high in the 1957 planting at Deception Creek (table 6) and indicates that significant year × location interaction could occur.

DISCUSSION

The results of this study indicate that the simple interest formula provides a reasonably accurate prediction of future infection of susceptible classes even though, for these three sites, there was a consistent overestimate. The simple interest model would overestimate: if spore distribution was nonrandom (Fracker 1936; Grogan and others 1980; Baker and Drury 1981); if environment at infection was nonrandom (Baker and Drury 1981); or if host or rust genotypes were nonrandom in distribution (Grogan and others 1980; Baker and Drury 1981). The consistently large overestimate of infection of resistant progenies also fits the above explanations. Presumably, there are some susceptible individuals among the progenies of resistant parents. These susceptible individuals become infected fairly early in life, whereas their resistant siblings remain free of rust even after a number of years of exposure. As a result, the family as a whole does not follow the expected ever-upward infection curve as predicted by the interest formula. In short, the potential infection in the resistant classes appears to be much below 100 percent. Our results are consistent with those reported for black rot of peanut and fusiform rust of southern pines (Hanounik and others 1977; Griggs and others 1978).

Whether judged on the basis of infection percentage or rate of infection, mating of trees with high general combining ability for resistance produced progeny with proportionally fewer susceptible individuals than other classes, and all classes performed relatively consistently over the various planting sites and years.

Variation also occurred in the mortality among resistance classes. Most of this variation can be attributed to high mortality of control lots in comparison to all other classes. Also, control crosses generally had lower mortality than open-pollinated lots. However, the greatest single factor affecting variation in mortality was planting year.

Resistant families should deviate from the expected just as families resistant to fusiform rust deviated (Griggs and others 1978) and families of sugar pine resistant to blister rust deviated (Kinloch 1981). On the other hand, we should expect some sites to give the expected 100 percent infection of susceptible material (Kinloch 1981).

Rust-related mortality of trees of GCA ×, GCA, and GCA OP resistance classes planted in 1957 at Emerald Creek and at all but the GCA × GCA class at Deception Creek in 1957 and in 1959 was much higher than that of trees planted at Priest River. In the case of trees planted in 1959 at Deception Creek and Emerald Creek, mortality was consistently higher than it was at Priest River for all classes. These data follow the patterns expected if a year favorable for rust infection occurring soon after stand establishment results in much higher mortality than severe rust years that occur later in the life of the stand (McDonald 1979), even though average annual infection rates are comparable.

Mortality necessarily is related to infection because a tree must be infected before it can be killed by the disease. However, in the current study many (in fact, most) infected trees did not die. There was little difference in proportion of trees infected by planting years with total infection ranging from 48 to 53 percent. In contrast, rust-caused mortality varies greatly, depending on year of establishment, resistant class, and location. Consequently, mortality was not closely related to infection rate. The correlation coefficient of mortality with infection rate was a significant 0.51, but this explains only about a fourth of the variation in mortality.

Further correlation analysis suggests that the more resistant classes are less subject to the year-to-year shift in mortality rate than are the highly susceptible classes. Correlation coefficients were 0.24 for the Controls and Other OP classes and 0.67 for the more resistant classes. An important conclusion is that susceptible trees are much more likely to be killed by heavy early infection than are resistant trees. Resistance decreases both infection rate and early mortality.

The mean infection rates and total infection percentages in 1980, 21 to 25 years after planting, clearly indicate that blister rust was more severe at Emerald Creek than at the other two locations (table 3). Mortality data also indicate the lesser hazard at the Priest River planting (table 6). But although these results today demonstrate the differences in rust hazard at these locations, how could a forest manager in 1955 have determined the relative hazard? And how could a manager today determine the hazard at other planting sites?

Disease incidence data from the volunteer trees should provide an independent assessment of the relative hazard at the three locations. However, our preliminary results (table 5) are more indicative of sampling problems than of the comparative hazard.

The small sample of volunteer pines taken at Emerald Creek provided only two to 10 trees per 1-year age class. Although these numbers appear to be inadequate, as most trees of all age classes were infected, perhaps a reasonable depiction of high hazard was presented. The mortality rate seems low, but volunteers were younger than planted trees. Time of exposure and age × infection year interaction could explain the discrepancy. Also, remnants of trees killed by rust early in life in this heavily infected stand may not have been detected.

Sampling among volunteers in the Priest River planting is suspect because silvicultural thinning was carried out in the naturally seeded stand, and this may have biased the results.

Only at Deception Creek were substantial numbers of trees sampled over the range of ages encountered. Here the infection rate increased with tree age. This may be due to the increase in susceptible tissue area as trees grow larger (McDonald and others 1981). Also, the amount of natural inoculum in an area varies from year to year, and wave years of heavy infection occur at irregular intervals when environmental conditions are favorable for development, distribution, and germination of sporidia. In this case, it may be that trees under 15 years old have not been exposed sufficiently to wave infection years. The oldest age group (21 to 25 years), the same ages as the planted pines, matched the infection rate (0.089) of the planted controls.

In any event, these data suggest that if natural white pine regeneration is to be used to assess blister rust hazard of an area:

1. Sampling should be careful and thorough. Particular attention should be paid to locating dead white pines and examining the base of the stems for possible cankers.
2. Sampling should be concentrated on the 16- to 20-year age class if such trees are available. Younger trees may not have been sufficiently exposed to heavy infection years. For older regeneration, it may not be possible to get a satisfactory count of early rust mortality.
3. If hazard at two or more locations is to be compared, the comparison should be based on trees of similar age.
4. Attention should be focused on site factors controlling the degree that infection will deviate from 100 percent in susceptible populations.
5. Concentration should be on infection rate because rust-caused mortality appears to be an unreliable indication of rust hazard. Not only is early mortality difficult to accurately assess in stands over 20 years old, but the amount of mortality appears to be strongly influenced by the age at which infection first occurs.

SUMMARY AND RECOMMENDATIONS

None of the locations in this study can be classed as having low rust hazard. Average infection rates of 11- to 20-year natural regeneration were: Deception Creek—0.06; Priest River—0.09; and Emerald Creek—0.35. If all classes and ages of material are included, one must conclude that Priest River and Deception Creek are about equal, and Emerald Creek is a very high-hazard location. Even a 0.05 annual infection rate translates to 63 percent infection by age 20 and over 90 percent infection and perhaps 50 percent mortality by age 50. Thus, satisfactory yields at rotation should not be expected with use of nonresistant stock at any of the three sites or sites like them.

Open-pollinated progenies of trees selected for resistance but not good general combiners had little superiority over the control lots. Also, the average resistance of open-pollinated progenies of all select trees combined, even though some of them were good combiners, was not high enough to justify their use in areas with infection rates as high as 0.05. Rust-caused losses related to the use of nonresistant stock or open-pollinated seed from untested phenotypically resistant parents would perhaps be tolerable in areas with an expected infection rate less than 2 percent.

Open-pollinated progenies of proven good combiners showed appreciable field resistance in these tests. Seed from such trees should be acceptable for planting sites of low-moderate hazard (sites on which nonresistant trees have 0.03 to 0.06 infection rates).

Crosses among good general combiners such as progenies of seed orchards containing only proven first-generation clones have adequate resistance for planting sites of moderate hazard such as the test sites at Priest River and Deception Creek. Sufficient trees should survive through a rotation of 60 years or more to provide satisfactory yields. However, on sites with hazard as great as that at Emerald Creek, trees with even this level of resistance may not achieve expected yields. Planting of sites showing a greater infection rate than Emerald Creek should definitely be restricted to the products of more advanced rust resistance breeding.

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Three white pine plantations, composed of materials of several levels of resistance from early generations of the blister rust resistance breeding program, were compared on the basis of annual infection and mortality rates. The sites varied in blister rust hazard; resistant materals were consistent in their performance, and the infection data behaved as one would expect if the genetic and environmental assumptions of the simple interest disease progress model were violated.

KEYWORDS: disease resistance, epidemiology, disease-hazard indexing, infection rate, epidemic analysis

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